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ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

INTRODUCTORY.

Some Thoughts on the Eye.—When we look at the world around us, on nature, we are impressed with its beauty and grandeur. Each thing we perceive, though it may be vanishingly small, is in itself a world; each, like the whole visible universe, is a world of matter and force governed by law—a world, the contemplation of which fills us with feelings of wonder and irresistibly urges us to ceaseless thought and inquiry. But in all this vast world, of all the objects our senses reveal to us, the most marvellous,

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893, and before the National Electric Light Association, at St. Louis, March 1, 1893.

the most appealing to our imagination, appears no doubt in highly developed organism, a thinking being. If there is anything fitted to make us admire nature's handiwork, it is certainly this inconceivable structure, which performs its innumerable motions in obedience to external influence. To understand its workings, to get a deeper insight into this nature's masterpiece, has ever been for thinkers a fascinating aim, and after many centuries of arduous research men have arrived at a fair understanding of the functions of its organs and senses. Again, in all the perfect harmony of its parts, of the parts which constitute the material or tangible of our being, of all its organs and senses, the eye is the most wonderful. It is the most precious, the most indispensable of our receptive or directive organs, it is the great gateway through which all knowledge enters the mind. Of all our organs, it is the one which is in the most intimate relation with that which we call intellect. So intimate is this relation, that it is often said, the very soul shows itself in the eye.

It can be taken as a fact, which the theory of the action of the eye implies that for each external impression; that is, for each image produced upon the retina, the ends of the visual nerves concerned in the conveyance of the impression to the mind, must be under a peculiar stress or in a vibratory state. It now does not seem improbable that, when by the power of thought an image is evoked, a distinct reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and therefore upon the retina. Will it ever be within human power to analyze the condition of the retina when disturbed by thought or reflex action, by the help of some optical or other means of such sensitiveness, that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems belonging to the domain of positive physical science, in the solution of which many, if not the majority, of scientific men implicitly believe. Helmholtz has shown that the fundi of the eyes are themselves luminous, and he

was able to *see*, in total darkness, the movement of his arm by the light of his own eyes. This is one of the most remarkable experiments recorded in the history of science, and probably only a few men could satisfactorily repeat it, for it is very likely that the luminosity of the eyes is associated with uncommon activity of the brain and great imaginative power. It is fluorescence of brain action, as it were.

There is another fact bearing on this subject, which has probably been noted by many, since it is stated in popular expressions, but which I cannot recollect to have found chronicled as a positive result of observation, viz: that at times, when a sudden idea or image presents itself to the intellect, there is a distinct and sometimes painful sensation of luminosity produced in the eye, and observable even in broad daylight.

The saying, then, that the soul shows itself in the eye, is deeply founded, and we feel that it expresses a great truth. It has a profound meaning even for one who, like a poet or artist, following only his inborn instinct or love for nature, finds delight in aimless thoughts and in the mere contemplation of natural phenomena, but a still more profound meaning for one who, in the spirit of positive scientific investigation, seeks to ascertain the causes of the effects. It is the natural philosopher, the physicist, for whom the eye is the subject of the most intense admiration.

Two facts about the eye must forcibly impress the mind of the physicist, notwithstanding he may think or say that it is an imperfect optical instrument, forgetting that the very conception of that which is perfect, or seems so to him, has been gained through this same instrument. Firstly, the eye is, as far as our positive knowledge goes, the only organ which is *directly* affected by that subtile medium, which as science teaches us, must fill all space; secondly, it is the most sensitive of our organs, incomparably more sensitive to external impressions than any other.

The organ of hearing requires the impact of ponderable bodies, the organ of smell the transference of detached material particles, and the organs of taste, and of touch or

force, the direct contact, or at least some interference of ponderable matter, and this is true even in those instances of animal organisms, in which some of these organs are developed to a degree of truly marvellous perfection. This being so, it seems wonderful that the organ of sight alone should be capable of being stirred by that which all our other organs are powerless to detect, which yet plays an essential part in all natural phenomena, which transmits all energy and sustains all motion and life, but which has properties such that even a scientifically trained mind cannot help drawing a distinction between it and all that is called matter. Considering merely this, and the fact that the eye, by its marvellous power, widens our otherwise very narrow range of perception far beyond the limits of the small world which is our own, and enables it to embrace myriads of other worlds, suns and stars in the infinite depths of the universe, it would seem justifiable to assert that the eye is an organ of a higher order than others. Its performances are beyond comprehension. Nature, as far as we know, never produced anything more wonderful. We can get barely a faint idea of its prodigious power by analyzing what it does and by comparing. When ether waves impinge upon the human body, they produce the sensations of warmth or cold, pleasure or pain, or perhaps other sensations of which we are not aware, and any degree or intensity of these sensations, which degrees are infinite in number, hence an infinite number of distinct sensations. But our sense of touch, or our sense of force, cannot reveal to us these differences in degree or intensity, unless they are very great. Now we can readily conceive how an organism, such as the human in the eternal process of evolution, or more philosophically speaking, adaptation to nature, being constrained to the use of only the sense of touch or force, for instance, might develop this sense to such a degree of sensitiveness or perfection, that it would be capable of distinguishing the minutest differences in the temperature of a body even at some distance, to a hundredth, or thousandth, or millionth part of a degree. Yet even this apparently impossible performance would not begin to compare with that of the

eye, which is capable of distinguishing and conveying to the mind in a single instant innumerable peculiarities of the body, be it in form or color or other respects. This power of the eye rests upon two things, namely, the rectilinear propagation of the disturbance by which it is affected, and its sensitiveness. To say that the eye is sensitive is not saying anything. Compared with it all other organs are monstrously crude. The organ of smell which guides a dog on the trail of a deer, the organ of touch or force which guides an insect in its wanderings, the organ of hearing, which is affected by the slightest disturbances of the air, are sensitive organs, to be sure, but what are they compared with the human eye? No doubt it responds to the faintest echoes or reverberations of the medium; no doubt, it brings us tidings from other worlds, infinitely remote, but in a language we cannot as yet always understand. And why not? Because we live in a medium filled with air and other gases and vapors and a dense mass of solid particles flying about. These play an important part in many phenomena; they fritter away the energy of the vibrations before they can reach the eye; they, too, are the carriers of germs of destruction, they get into our lungs and other organs, clog up the channels, and imperceptibly yet inevitably arrest the stream of life. Could we but do away with all ponderable matter in the line of sight of the telescope, it would reveal to us umdreamt-of marvels. Even the unaided eye, I think, would be capable of distinguishing in the pure medium, small ojects at distances measured probably by hundreds or perhaps thousands of miles.

But there is something else about the eye which impresses us still more than these wonderful features which we observe, viewing it from the standpoint of a physicist, merely as an optical instrument—something which appeals to us more than its marvellous faculty of being directly affected by the vibrations of the medium, without interference of gross matter, and more than its inconceivable sensitiveness and discerning power. It is its significance in the processes of life. No matter what one's views of nature and life may be, he must stand amazed when, for the first time in his

thoughts, he realizes the importance of the eye in the physical processes and mental performances of the human organism. And how could it be otherwise, when he realizes that the eye is the means through which the human race has acquired the entire knowledge it possesses, that it controls all our motions, more still, all our actions.

There is no way of acquiring knowledge except through the eye. What is the foundation of all philosophical systems of ancient and modern times; in fact, of all the philosophy of man? *I am, I think; I think; therefore, I am.* But how could I think and how would I know that I exist if I had not the eye? For knowledge involves consciousness; consciousness involves ideas, conceptions; conceptions involve pictures or images, and images the sense of vision, and, therefore, the organ of sight. But how about blind men, will be asked? Yes, a blind man may depict in magnificent poems forms and scenes from real life, from a world he physically does not see. A blind man may touch the keys of an instrument with unerring precision, may build the fastest boat, may discover and invent, calculate and construct, may do still greater wonders—but all the blind men who have done such things have descended from those who had seeing eyes. Nature may reach the same result in many ways. Like a wave in the physical world, in the infinite ocean of the medium which pervades all, so in the world of organisms, in life, an impulse started proceeds onward, at times, may be, with the speed of light, at times, again, so slowly, that for ages and ages it seems to stay, passing through processes of a complexity inconceivable to men, but in all its forms, in all its stages, its energy ever and ever integrally present. A single ray of light from a distant star falling upon the eye of a tyrant in by-gone times, may have altered the course of his life, may have changed the destiny of nations, may have transformed the surface of the globe, so intricate, so inconceivably complex are the processes in nature. In no way can we get such an overwhelming idea of the grandeur of nature as when we consider that in accordance with the law of the conservation of energy, throughout the infinite, the forces are

in a perfect balance, and hence the energy of a single thought may determine the motion of a universe. It is not necessary that every individual, not even that every generation or many generations, should have the physical instrument of sight, in order to be able to form images and to think; that is, to form ideas or conceptions; but at some time or other, during the process of evolution, the eye certainly must have existed; else thought, as we understand it, would be impossible; else conceptions, like spirit, intellect, mind, call it as you may, could not exist. It is conceivable, that in some other world, in some other beings, the eye is replaced by a different organ, equally or more perfect, but these beings cannot be men.

Now, what prompts us to all voluntary motions and actions of any kind? Again, the eye. If I am conscious of the motion, I must have an idea or conception; that is, an image; therefore the eye. If I am not precisely conscious of the motion, it is because the images are vague or indistinct, being blurred by the superimposition of many. But when I perform the motion, does the impulse which prompts me to the action come from within or from without? The greatest physicists have not disdained to endeavor to answer this and similar questions, and have at times abandoned themselves to the delights of pure and unrestrained thought. Such questions are generally considered not to belong to the realm of positive physical science, but before long they will be annexed to its domain. Helmholtz has probably thought more on life than any other modern scientist. Lord Kelvin expressed his belief that life's process is electrical and that there is a force inherent in the organism and determining its motions. Just as much as I am convinced of any physical truth, I am convinced that the motive impulse must come from the outside. For, consider the lowest organism we know—and there are probably many lower ones—an aggregation of a few cells only. If it is capable of voluntary motion it can perform an infinite number of motions, all definite and precise. But now a mechanism consisting of a finite number of parts and a few at that, cannot perform an infinite number of definite motions; hence the impulses

which govern its movements must come from the environment. So, the atom, the ulterior element of the universe's structure, is tossed about in space eternally, the toy of external influences, like a float in a troubled sea. Were it to stop its motion *it would die.* Matter at rest, if such a thing could exist, would be matter dead. Death of matter! Never has a sentence of deeper philosophical meaning been uttered. This is the way in which Professor Dewar forcibly expresses it in the description of his admirable experiments, in which liquid oxygen is handled as one handles water, and air at ordinary pressure is made to condense and even to solidify by the intense cold: experiments, which serve to illustrate, as he says, the last feeble manifestations of life, the last quiverings of matter about to die. But human eyes shall not witness such death. There is no death of matter, for throughout the infinite universe, all has to move, to vibrate; that is, to live.

I have made the preceding statements at the peril of treading upon metaphysical ground in my desire to introduce the subject of this lecture in a manner not altogether uninteresting, I may hope, to an audience such as I have the honor to address. But now, then, returning to the subject, this divine organ of sight, this indispensable instrument for thought and all intellectual enjoyment, which lays open to us the marvels of this universe, through which we have acquired what knowledge we possess, and which prompts us to, and controls, all our physical and mental activity. By what is it affected? By light! What is light?

We have witnessed the great strides which have been made in all departments of science in recent years. So great have been the advances that we cannot refrain from asking ourselves, Is this all true, or is it but a dream? Centuries ago men lived, thought, discovered, and invented, and they believed that they were soaring, while they were merely proceeding at a snail's pace. So we, too, may be mistaken. But taking the truth of the observed events as one of the implied facts of science, we must rejoice in the immense progress already made and still more in the anticipation of what must come, judging from the

possibilities opened up by modern research. There is, however, an advance which we have been witnessing, which must be particularly gratifying to every lover of progress. It is not a discovery, or an invention, or an achievement in any particular direction. It is an advance in all directions of scientific thought and experiment. I mean the generalization of the natural forces and phenomena, the looming up of a certain broad idea on the scientific horizon. It is this idea, which, however, long ago took possession of the most advanced minds, to which I desire to call your attention, and which I intend to illustrate, in a general way, in these experiments, as the first step in answering the question, "What is light?" and to realize the modern meaning of this word.

It is beyond the scope of my lecture to dwell upon the subject of light in general, my object being merely to bring presently to your notice a certain class of light effects and a number of phenomena observed in pursuing the study of these effects. But to be consistent in my remarks, it is necessary to state that according to that idea, now accepted by the majority of scientific men as a positive result of theoretical and experimental investigation, the various forms or manifestations of energy which were generally designated as "electric" or more precisely "electro-magnetic" are energy manifestations of the same nature as those of radiant heat and light. Therefore, the phenomena of light and heat, and others besides these, may be called electrical phenomena. Thus, electrical science has become the mother science of all and its study has become all important. The day when we shall know exactly what "electricity" is, will chronicle an event probably greater, more important, than any other recorded in the history of the human race. The time will come when the comfort, perhaps the very existence, of man will depend upon that wonderful agent. For our existence and comfort we require heat, light and mechanical power. How do we now get all these? We get them from fuel, we get them by consuming material. What will man do when the forests disappear; when the coal fields are exhausted? Only one

thing, according to our present knowledge, will remain; that is, to transmit power at great distances. Men will go to the waterfalls, to the tides, which are the stores of an infinitesimal part of nature's immeasurable energy. There will they harness the energy and transmit the same to their settlements, to warm their homes, to give them light and to keep their obedient slaves, the machines, toiling. But how will they transmit this energy if not by electricity? Judge then, if the comfort, nay, the very existence of man, will not depend on electricity. I am aware that this view is not that of a practical engineer, but neither is it that of an illusionist, for it is certain, that power transmission, which at present is merely a stimulus to enterprise, will some day be a dire necessity.

It is more important for the student who takes up the study of light phenomena, to make himself thoroughly acquainted with certain modern views, than to peruse entire books on the subject of light itself, as disconnected from these views. Were I therefore to make these demonstrations before students seeking information—and for the sake of the few of these who may be present, give me leave to so assume—it would be my principal endeavor to impress these views upon their minds in this series of experiments.

It might be sufficient for this purpose to perform a simple and well-known experiment. I might take a familiar appliance, a Leyden jar, charge it from a frictional machine, and then discharge it. In explaining to you its permanent state when charged, and its transitory condition when discharging, calling your attention to the forces which enter into play and to the various phenomena they produce, and pointing out the relation of the forces and phenomena, I might fully succeed in illustrating that modern idea. No doubt, to the thinker, this simple experiment would appeal as much as the most magnificent display. But this is to be an experimental demonstration, and one which should possess besides instructive, also entertaining features; and as such, a simple experiment, such as the one cited, would not go very far towards the attainment of the lecturer's aim. I must therefore choose another way of illustrating, more

spectacular certainly, but perhaps also more instructive. Instead of the frictional machine and Leyden jar, I shall avail myself in these experiments of an induction coil of peculiar properties, which was described in detail by me in a lecture before the London Institution of Electrical Engineers, in February, 1892. This induction coil is capable of yielding currents of enormous potential differences, alternating with extreme rapidity. With this apparatus I shall endeavor to show you three distinct classes of effects, or phenomena, and it is my desire that each experiment, while serving for the purposes of illustration, should at the same time teach us some novel truth, or show us some novel aspect of this fascinating science. But before doing this, it seems proper and useful to dwell upon the apparatus employed, and upon the method of obtaining the high potentials and high frequency currents which are made use of in these experiments.

On the Apparatus and Method of Conversion.—These high frequency currents are obtained in a peculiar manner. The method employed was advanced by me about two years ago in an experimental lecture before the American Institute of Electrical Engineers. A number of ways, as practised in the laboratory, of obtaining these currents either from continuous or low frequency alternating currents is diagrammatically indicated in *Fig. 1*, which will be later described in detail. The general plan is to charge condensers, from a direct or alternate current source, preferably of high tension, and to discharge them disruptively while observing well-known conditions necessary to maintain the oscillations of the current. In view of the general interest taken in high frequency currents and in the effects producible by them, it seems to me advisable to dwell at some length upon this method of conversion. In order to give you a clear idea of the action, I will suppose that we employ a continuous current generator which is often very convenient. It is desirable that the generator should possess such high tension as to be able to break through a small air space. If this is not the case, then auxiliary means have to be resorted to, some of which will be indicated subsequently. When the conden-

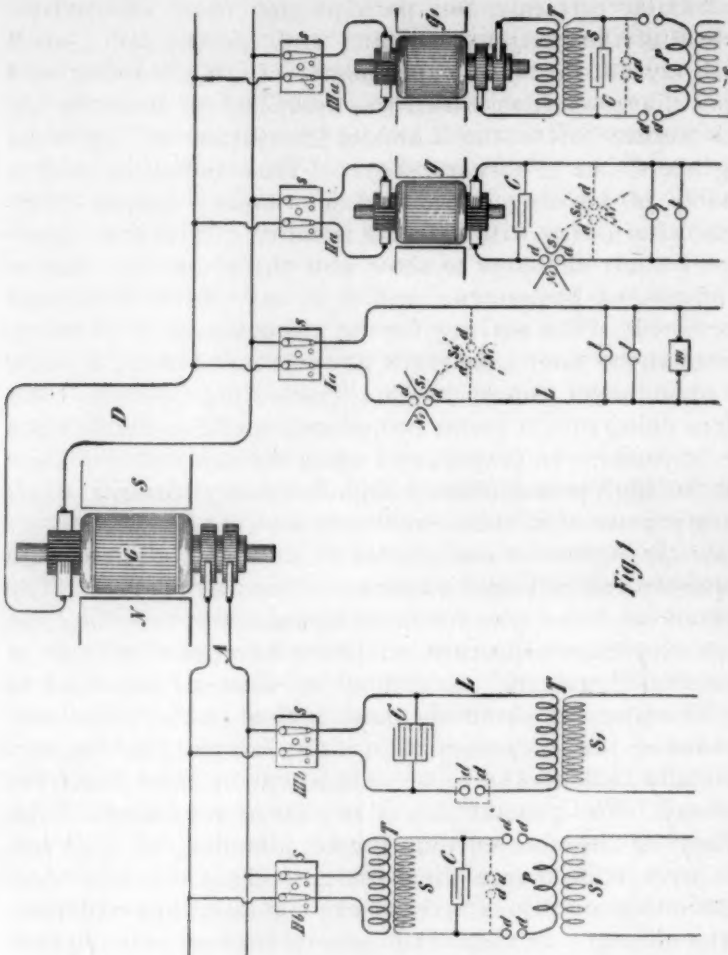

FIG. 1.—Plan of connection used in the conversion by means of the disruptive arc discharge.

sers are charged to a certain potential, the air or insulating space gives way and a disruptive discharge occurs. There is then a sudden rush of current and generally a large portion of

the accumulated electrical energy spends itself. The condensers are thereupon quickly charged and the same process is repeated in more or less rapid succession. To produce such sudden rushes of current it is necessary to observe certain conditions. If the rate at which the condensers are discharged is the same as that at which they are charged, then, clearly, in the assumed case the condensers do not come into play. If the rate of discharge be smaller than the rate of charging, then, again, the condensers cannot play an important part. But if, on the contrary, the rate of discharging is greater than that of charging, then a succession of rushes of current is obtained. It is evident that if the rate at which the energy is being dissipated by the discharge is very much greater than the rate of supply to the condensers, the sudden rushes will be comparatively few, with long-time intervals between. This always occurs when a condenser of considerable capacity is charged by means of a comparatively small machine. If the rates of supply and dissipation are not widely different, then the rushes of current will be in quicker succession, and the more so, the more nearly equal both rates are, until natural limitations, incident to each case and depending upon a number of causes, are reached. Thus we are able to obtain from a continuous current generator as rapid a succession of discharges as we like. Of course, the higher the tension of the generator, the smaller need be the capacity of the condensers, and for this reason, principally, it is of advantage to employ a generator of very high tension. Besides, such a generator permits the attaining of greater rates of vibration.

The rushes of current may be of the same direction under the conditions before assumed, but most generally there is an oscillation superimposed upon the fundamental vibration of the current. When the conditions are so determined that there is no oscillation, the current impulses are unidirectional and thus a means is provided of transforming a continuous current of high tension into a direct current of lower tension, which I think may find employment in the arts.

This method of conversion is exceedingly interesting, and

I was much impressed by its beauty when I first conceived it. It is ideal in certain respects. It involves the use of no mechanical devices of any kind, and it allows of obtaining currents of any desired frequency from an ordinary circuit, direct or alternating. The frequency of the fundamental discharges, depending as it does on the relative rates of supply and dissipation, can readily be varied within wide limits by simple adjustments of these quantities, and the frequency of the superimposed vibration by the determination of the capacity, self-induction and resistance of the circuit. The potential of the currents, again, may be raised as high as any insulation is capable of withstanding safely, by combining capacity and self-induction, or by induction in a secondary, which need have but comparatively few turns.

As the conditions are often such that the intermittence or oscillation does not readily establish itself, especially when a direct current source is employed, it is of advantage to associate an interrupter with the arc, and I indicated, some time ago, the use of an air-blast or magnet, or other such device readily at hand. The magnet is employed with special advantage in the conversion of direct currents, as it is then very effective. If the primary source is an alternate current generator, it is desirable, as I stated on a former occasion, that the frequency should be low, and that the currents forming the arc be large, in order to render the magnet more effective.

A form of such discharger with a magnet, which has been found convenient and adopted after some trials, in the conversion of direct currents particularly, is illustrated in *Fig. 2*. *N* and *S* are the pole pieces of a very strong magnet which is excited by a coil *C*. The pole pieces are slotted for adjustment and can be fastened in any position by screws s_1 s_1. The discharge rods d d_1 thinned down on the ends in order to allow a closer approach of the magnetic pole pieces, pass through the columns of brass b b_1 and are fastened in position by screws s_2 s_2. Springs r r_1 and collars c c_1 are slipped on the rods, the latter serving to set the points of the rods at a certain suitable distance by means of screws s_3 s_3, and the former to draw the points apart. When it is

desired to start the arc, one of the hard rubber handles h h_1 is tapped quickly with the hand, whereby the points of the rods are brought in contact, but are instantly separated by springs r r_1. Such an arrangement has been found to be often necessary, namely, in cases when the E. M. F. was not great enough to cause the discharge to break through the gap, and also when it was desirable to avoid short-circuiting of the generator by the metallic contact of the rods. The rapidity of the interruptions of the current with a magnet depends on the intensity of the magnetic field and on the potential difference at the ends of the arc. The interruptions are generally in such quick succession as to produce a

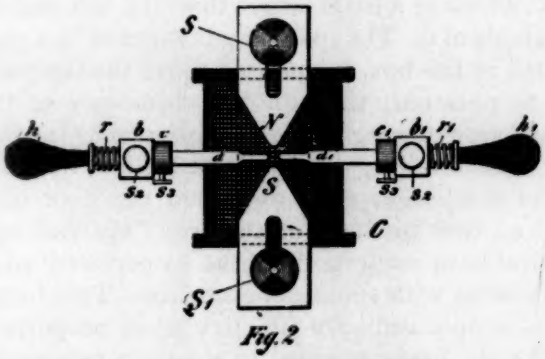

Fig. 2

FIG. 2.—Form of discharger with magnet used in the direct-current conversion.

musical sound. Years ago it was observed that when a powerful induction coil is discharged between the poles of a strong magnet, the discharge produced a loud noise not unlike a small pistol shot. It was vaguely stated that the spark was intensified by the presence of the magnetic field. It is now clear that the discharge current, flowing for some time, was interrupted a great number of times by the magnet, thus producing the sound. The phenomenon is especially marked when the field circuit of a large magnet or dynamo is broken in a powerful magnetic field.

When the current through the gap is comparatively large, it is of advantage to slip on the points of the dis-

charge rods pieces of very hard carbon and let the arc play between the carbon pieces. This preserves the rods, and besides has the advantage of keeping the air space hotter, as the heat is not conducted away as quickly through the carbons. The result is that a smaller E. M. F. in the arc gap is sufficient to maintain a succession of discharges.

Another form of discharger which may be employed with advantage in some cases is illustrated in *Fig. 3*. In this form the discharge rods $d\ d_1$ pass through perforations in a wooden box B, which is thickly coated with mica on the inside, as indicated by the heavy lines. The perforations are provided with mica tubes $m\ m_1$ of some thickness, which are preferably not in contact with the rods $d\ d_1$. The box has a cover C, which is a little larger than the box and descends on the outside of it. The spark gap is warmed by a small lamp l contained in the box. A plate p above the lamp allows the draught to pass only through the chimney c of the lamp, the air entering through holes $o\ o$ in or near the bottom of the box and following the path indicated by the arrows. When the discharger is in operation the door of the box is closed so that the light of the arc is not visible outside. It is desirable to exclude the light as perfectly as possible, as it interferes with some experiments. This form of discharger is simple and very effective when properly manipulated. The air, being warmed to a certain temperature, has its insulating power impaired. It becomes dielectrically weak, as it were, and the consequence is that the arc can be established at much greater distance. The air should, of course, be sufficiently insulating to allow the discharge to pass through the gap *disruptively*. The arc formed under such conditions, when long, may be made extremely sensitive, and the weak draught through the lamp chimney c is quite sufficient to produce rapid interruptions. The adjustment is made by regulating the temperature and velocity of the draught. Instead of using a lamp, it answers the purpose to provide for a draught of warm air in other ways. A very simple way which has been practised is to inclose the arc in a long vertical tube with plates on the top and bottom for regulating the temperature and velocity

of the air current. Some provision had to be made for deadening the sound.

The air may be rendered dielectrically weak also by rarefaction. Dischargers of this kind have likewise been used by me in connection with the magnet. For this purpose a large tube is provided with heavy electrodes of carbon or metal, between which the discharge is made to pass, the tube being placed in a powerful magnetic field. The exhaustion of the tube is carried to a point at which the discharge breaks through easily, but the pressure should be more than seventy-five millimetres, at which the ordinary

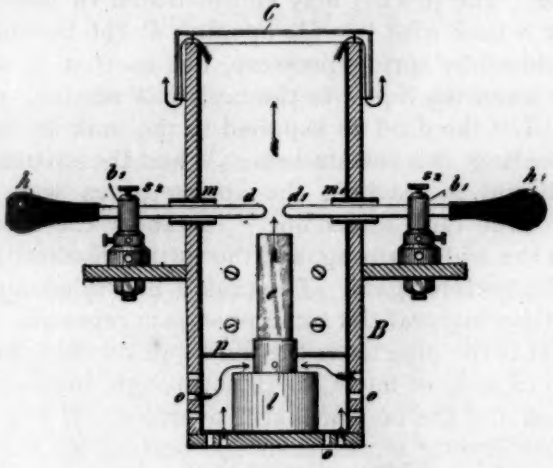

Fig. 3

FIG 3.—Discharger with hot-air draft.

thread discharge occurs. In another form of discharger, combining the features before mentioned, the discharge was made to pass between two adjustable magnetic pole pieces, the space between them being kept at an elevated temperature.

It should be remarked here that when interrupting devices of this or any other kind are used, and the currents are passed through the primary of a disruptive discharge coil, it is not, as a rule, of advantage to produce a number of interruptions of the current per second greater than the natural frequency of vibration of the dynamo supply circuit,

which is ordinarily small. It should also be pointed out here, that while the devices mentioned in connection with the disruptive discharge are advantageous under certain conditions, they may sometimes be a source of trouble, as they produce intermittences and other irregularities in the vibration which it would be very desirable to overcome.

There is, I reget to say, in this beautiful method of conversion, a defect, which fortunately is not vital, and which I have been gradually overcoming. I can best call attention to this defect and indicate a fruitful line of work by comparing the electrical process with its mechanical analogue. The process may be illustrated in this manner: Imagine a tank with a wide opening at the bottom, which is kept closed by spring pressure, but so that it snaps off *suddenly* when the liquid in the tank has reached a certain height. Let the fluid be supplied to the tank by means of a pipe feeding at a certain rate. When the critical height of the liquid is reached, the spring gives way and the bottom of the tank drops out. Instantly the liquid falls through the wide opening, and the spring, reasserting itself, closes the bottom again. The tank is now filled, and after a certain time interval the same process is repeated. But it is clear that if the pipe feeds the fluid quicker than the bottom outlet is capable of letting it pass through, the bottom will remain off and the tank will still overflow. If the rates of supply are exactly equal, then the bottom lid will remain partially open and no vibration of the same and of the liquid column will generally occur, though it might, if started by some means. But if the inlet pipe does not feed the fluid fast enough for the outlet, then there will always be vibration. Again, in such case, each time the bottom flaps up or down, the spring and the liquid column, if the pliability of the spring and the inertia of the moving parts are properly chosen, will perform independent vibrations. In this analogue the fluid may be likened to electricity or dielectric, and the pipe to the conductor through which electricity is supplied to the condenser. To make this analogy quite complete it is necessary to make the assumption that the bottom, each time it gives way, is knocked violently against

a non-elastic stop, this impact involving some loss of energy, and that, besides, some dissipation of energy results, due to frictional losses. In the preceding analogue the liquid is supposed to be under a steady pressure. If the pressure of the fluid be assumed to vary rhythmically, this may be taken as corresponding to the case of an alternating current. The process is then not so easily followed, but then action is the same in principle.

[*To be continued.*]

PRESENT DEVELOPMENT OF HEAVY ORDNANCE IN THE UNITED STATES.

By W. H. JAQUES, Ordnance Engineer.

[*A lecture delivered before the Franklin Institute, January 6, 1893.*]

The lecturer was introduced by the Secretary of the Institute and spoke as follows:

MR. CHAIRMAN AND MEMBERS OF THE INSTITUTE:

A few days after the issue of the notice by your Institute that I would come here to-night for the purpose of telling you something about recent progress in the United States in the manufacture of heavy ordnance, I received a letter from a friend which I shall take the liberty of reading to you:

"It affords me pleasure to be the recipient of cards for a lecture to be delivered by you at the Franklin Institute on Friday, January 6, 1893, and I thank you for the opportunity you have so kindly afforded me to listen to your essay on the 'Recent Development of Heavy Ordnance in the United States.' I shall be there and shall look forward to hearing something new and interesting on that occasion."

In my response to him I wrote:

"Replying to your favor of the 24th, when you recall departmental and manufacturing reticence, you will perhaps not be surprised if you do not hear anything new," and this must be my excuse for doing little more than repeat

in a revised form my lecture delivered to the New York Naval Reserve Association last May.

As our good friend, Mr. Kirchhoff, has already made you familiar with the major part of it through the columns of his excellent journal, *The Iron Age*, I shall have to ask your indulgence to consider that publication as taking the place of the advance copies of papers usually distributed to their members by scientific societies.

As stated as a prelude to that lecture, in these days when the representatives of our press so readily familiarize themselves with the details of technical subjects, it is very difficult to describe operations, give results of tests, or suggestions as to future experiments without encroaching more or less upon information already given; for it must not be forgotten that in the splendid organizations of the press of this country there exist technical staffs whose members not only report the results of experiments that are made, but, as a consequence of the study and research which enables them to make the intelligent reports they give us, are also competent to make valuable suggestions to those who are engaged in developing the various arms.

In describing the construction of heavy ordnance I shall keep within a period of ten years, since, with the exception of increasing the size of the parts and decreasing their number, there has been no radical change from the recommendations of the Gun Foundry Board which were confirmed by the Senate Ordnance Committees; and, although all the leading nations have been studiously searching for, and experimenting with, new types, we find ourselves to-day employing for service guns those recommended by these committees.

The decrease of the number of parts was a natural sequence of the development of the means in the United States for the certain production of these increased integers. This practice has continued until we have reached the type advocated by Mr. Gledhill, in 1886, in which the few cylindrical or conical parts that are used to make up the gun are assembled, after taper machining, under great hydraulic pressure, either alone or in combination with screwing and proper shrinkage.

During this period no great change in the composition of steel for guns has been accepted, although alloys containing manganese, chrome, tungsten, copper, nickel, aluminum, etc., have been suggested and tried, with the view of securing increased hardness to resist the erosion, or a greater elastic strength to control the pressures that have accompanied the higher velocities.

Nitro-compound powders have been developed and successful results are reported where the highest service velocities have been obtained with half of the charges of brown powder previously employed. The enduring qualities of these so-called smokeless powders are doubted by many artillerists, but I have recently had the pleasure of receiving a visit from Mr. Alexander Anderson, who for many years was associated with Professor Abel, at the Royal Laboratory, Woolwich Arsenal, England, and who is credited with having perfected and patented the well-known smokeless powders whose methods of production are now controlled by the Chillworth Company. Of the stability of this new powder he assures me there is no doubt.

Referring further to what has been accomplished in Great Britain with the new powders, another English authority writes:

"In 1877, Capt. Andrew Noble, C.B., F.R.S., acting in conjunction with Sir Frederick Abel, F.R.S., carried out experiments to determine the action of gunpowder. These researches led to the construction by Elswick of six-inch and eight-inch guns, with which velocities up to 2,100 feet per second were obtained. And this important advance was followed everywhere by the use of the slow-burning powders in guns of increased length. With modern powder the velocities of the most powerful armor piercing guns may be taken at from 2,000 to 2,100 foot-seconds. But we are not at all at the end of progress, and as investigations in powder are carried on, even better results will probably be obtained.

With "amide" powder nearly 2,500 feet velocity has indeed already been obtained from a six-inch gun with moderate pressures, and a new explosive called "cordite,"

recommended by the Committee on Explosives, has given even better results than this."

With a charge of nineteen and one-half pounds of this powder a muzzle velocity of 2,669 feet has been obtained with the six-inch quick-firing gun.

"Of ballistite, and the host of other explosives now being introduced, we need not here speak, because they have not yet passed the experimental stage.

"Perhaps the most promising is cordite, resembling long pieces of thin black or gray cord. The climatic trials of cordite are, however, not yet complete. Many of the mixtures of this kind are very apt to deteriorate by keeping, and to become uncertain in action in hot climates, and experiments in this direction must always be very completely carried out before the final adoption of an explosive. One of the causes which has made gunpowder so successful an agent for the purposes of the artillerist, is that it is a mechanical mixture, not a definite chemical combination, and that it is practically impossible to detonate it."

Reports from France speak enthusiastically of the results that French chemists and artillerists have obtained.

Our own officials state that the macaroni form has been adopted and that repeated experiments have further demonstrated its stability and safety.

Duff Grant, in his lecture delivered before the United Service Club of New York, December 17, 1892, gave an interesting comparison of the qualities of the old and new powders. He is Secretary of the Smokeless Powder Company, of London, and as such presented the productions of his company in the most favorable light; but even he tells of the danger of most of the nitro types.

Longridge, in April, 1892, in his advocacy of a more powerful field gun than that in use in the British service, based his proposals on the use of Nobel powder, stating that although he possessed very limited information respecting cordite, he had reason to believe that there would not be any great difference in the results were cordite substituted for the Nobel powder. Yet in the same paper he thanks the "*new powders*" for the immense progress already realized

and expected in ballistic power, but calls attention to their increased pressures, which he thinks the wire system of construction* will be utilized to resist.

Speaking further of them, he says: "It is a common error to suppose that these powders are a new discovery: they have been known in substance for the last thirty or forty years. What is new, is the improvement in the means of controlling their rate of combustion, so as to regulate the development of the pressure and permit of their safe use in guns. It now remains to adapt the guns to the new powders, so as with safety to utilize their vastly superior force."

But even Longridge, with all his enthusiastic claim for the incontestable superiority of the new powder, calls attention to the danger to be guarded against from the very fact of its being a so much more powerful agent.

Many interesting and successful experiments have been made, each nation claiming for its own invention the greatest amount of usefulness and stability. Few military questions are discussed now with more fervor than that of the advantages and disadvantages of these nitro-explosives. Their advocates say: *My* powders can be used by anybody without fear; but they generally add: The greatest care, however, must be employed in their use. To which last statement their opponents point as indicating a well-known existence of danger that must not be overlooked.

In adhering to the built-up system of forged steel as the best type of gun construction, it is not with a feeling that some other type may not take its place and perhaps be more successful, but because we know all about it, what it will do, the strength of every part and how to insure it.

If anyone had assured us twenty years ago that cars would be speeding along rails at the rate of thirty miles an hour without horse or steam or cable power, simply by a force transmitted through wires; that we could talk over a wire for a distance of 1,000 miles with greater ease and distinctness than through the ordinary speaking tube; that

* Lantern view.

aluminum could be bought for fifty cents a pound; that colors could be photographed; that photograph-telegraphy would be accomplished; we would have received his statements with great incredulity and would have listened to such suggestions with even less faith, if it were possible, than we now receive the prediction of Lieutenant Totten in regard to the destruction of the world; or, if we could have accepted them, would have regarded our informant as possessing miraculous foresight.

Therefore, while I accept the built-up forged steel gun as the best because I know how it can be made a perfect machine, and because I can recommend its being put into service without fear of its doing more harm to its friends than to its enemies, I have no desire to discourage the enthusiastic supporters of other types, for they may succeed as others have done before them, and the built-up forged steel, high power, breech-loading gun may be as permanently superseded as iron has been supplanted and replaced by steel.

Instead of suggesting designs for revolutionizing the present accepted type, I will proceed with the details of its manufacture.

You are all familiar with the production of the pig in the blast furnace,* the parts, method of filling and blowing in, action and operation of the furnace and its accessories.

As the American furnaces have jumped to the front in the production of pig iron, it may be interesting to recall the dimensions of one of the largest. It was built in 1885–86: has a total height of 80 feet; diameter of hearth, 11 feet; diameter of bosh, 23 feet; the bell is 12 feet in diameter, and the stock line 16 feet; the cubical capacity is 19,800 feet; it has seven tuyeres of 6-inch diameter. The blast was used at a temperature of 1,200°, entering the tuyeres at a pressure of from nine to ten pounds. The highest monthly output was 12,706 gross tons, or an average of nearly 410 tons per day.

In reply to inquiries concerning the data just mentioned,

* Lantern view.

Messrs. Swank and Birkinbine kindly sent me the following letters:

THE AMERICAN IRON AND STEEL ASSOCIATION.

PHILADELPHIA, January 3, 1893.

Lieut. W. H. Jaques, South Bethlehem, Pa.

DEAR MR. JAQUES—I have received your letter of yesterday. The furnace you speak of, by a singular coincidence, is identical in height, diameter of hearth and diameter of bosh, with one of the Edgar Thomson furnaces which performed such good work under Mr. Gayley's management, in 1886 and 1887, and again in 1888, 1889 and 1890, that Mr. Gayley was induced to write up its record for the meeting of the British Iron and Steel Institute at New York in October, 1890. * * * Very truly yours,

JAMES M. SWANK.

THE AMERICAN INSTITUTE OF MINING ENGINEERS.

PHILADELPHIA, January 3, 1893.

Lieut. W. H. Jaques, South Bethlehem, Pa.

MY DEAR SIR—I have your favor of the 3d, giving me the dimensions of what I take to be one of the Edgar Thomson furnaces, and asking if I have anything larger than this on my record. I do not think there is now anything larger in the United States, unless it be one of the other furnaces of the Edgar Thomson Works, some of which are ninety feet high. The tendency has been rather to keep within moderate limits, and some of the very large furnaces have been lined to smaller diameters than their original construction planned.

Between 1865 and 1873 there was a tendency in Great Britain to construct very large furnaces, but I understand most of these have been reduced in size. Below I give you the dimensions of some:

Feet High.	*Feet Bosh.*	*Feet Capacity.*
85	25	26,000
95½	22	25,940
95½	23	28,800
80	25	25,000
80	24	24,613
90	30	41,149
85	27	32,000
85	28	30,000
95½	24	28,950

Fully twenty-five furnaces were built of these large dimensions, but when it comes to production in comparison to the cubical contents, our English cousins are "not in it" in comparison with us. Trusting this may be of service, I am, Yours truly,

JOHN BIRKINBINE.

Although Krupp uses the crucible process almost exclusively and Russia employs it largely, most of the gun steel,

and all of it in the United States, is made by the open hearth process, the metal being melted in *open hearth* instead of in closed pots or crucibles. Steel made by other processes than the open hearth and crucible has shown physical characteristics equal to and in some cases more remarkable than those which fulfil the present requirements; but when such steels were used for gun construction it was found that they were not adapted to the purpose.

There are many forms of the open hearth furnace, differing in arrangement of regenerators, valves, shape of hearth and slope of roof, but their general construction will be understood from the accompanying view of a Siemens regenerative gas furnace.*

After the sole or bottom of refractory sand has been made and the hearth has been brought to a full heat, the raw materials, iron ore, pig iron, wrought-iron blooms, and steel scrap are put in through the doorways, generally in a solid state. As soon as the whole charge has been fully melted a series of tests is begun, which usually consists in taking samples in small ladles and casting them into small test ingots. These are cooled and broken and by the changing indication of the fracture and carbon determinations, as the process advances, the exact condition of the bath is obtained.

The reduction of the carbon is continued until it stands at the required percentage, when the bath is recarburized, by the introduction of a quantity of preheated spiegel or ferro-manganese, after which the metal is stirred and the contents of the furnace tapped into a ladle.*

The ladle is then transferred by rail to the fluid compression plant* where the steel is compressed or run into the moulds for which the metal has been intended.

The sizes of the ladles are governed by the capacity of the furnaces and the class of work for which the steel is to be used. Of heavy iron construction, they are lined with a refractory mixture and pierced in two places in the bottom for the insertion of fire-brick nozzles, through which the metal runs into the moulds. Into these nozzles clay-plum-

* Lantern view.

bago stoppers are fitted and attached to heavy rods which extend upward and out over the side of the ladle to the levers or other attachments provided for lifting and controlling them. The device shown in the view* is a simple and effective one.

The moulds are of steel, iron, brick, or sand, and are of dimensions and shapes suited to the purpose for which the ingot or casting is to be used.

Bethlehem has four open-hearth melting furnaces, of the respective capacities of fifteen, thirteen, and two forty tons.

The Whitworth system of fluid compression consists in compressing the liquid metal in a mould immediately after pouring. The moulds are tapered cylinders made of steel and lined with refractory material. As soon as the mould is filled it is moved under the fixed head of the press* and the pressure applied.

As soon as the ingot has cooled and contracted sufficiently, the mould is removed by the crane*, and the ingot is lifted out of the casting-pit and taken to the heating furnace to be raised to the forging temperature.

These heating furnaces are of the general Siemens regenerative type, with large doors in front and rear, operated by hydraulic power and with spacious heating chambers to admit the largest work. When the ingot or block is raised to the needful temperature it is removed from the furnace and put under the hydraulic forging press* to be shaped. This press consists of a massive head and bottom secured by four forged steel columns held together by nuts. The head carries the hydraulic cylinder and ram with which the work is done upon the piece to be forged as it rests upon the anvil. The piece upon the anvil in the view* before you is a hollow forging, the hole in the block having been bored or punched previous to putting it into the heating furnace. The press is fitted with cranes and other mechanical contrivances for the handling of the forging while it is being shaped.

The operations of drawing out a tube and enlarging a

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* Lantern view.

hoop by this method are represented in the following sketches.* Into the heated hollow ingot a steel mandrel is inserted and both are placed between suitable dies fitted to the ram and anvil. As repeated pressures are given, the ingot and mandrel are turned round into fresh positions, and, as the metal cannot flow except in the direction of the length, the tube is reduced to the required diameter and drawn out to the requisite length.

This view* represents a hollow cylinder weighing 28,250 pounds; 44 inches exterior diameter; 60 inches long, with a hole 14½ inches diameter.

It is represented here* before forging and was drawn down in one heat to a hollow cylinder 160 inches long; 30 inches exterior diameter, with the hole reduced to 14 inches, as shown here.*

These two figures* represent the operation of drawing out a solid ingot (which before forging was 92 inches long and 42 inches diameter) in one heat to the shape represented here.* In this heat half of it has been drawn into a forging twenty inches in diameter; if the remaining portion is to be reduced to the same size, that not reduced will be re-heated and drawn down in the same manner.

The two figures* on the left represent the result of the operation of enlarging a hoop, which is shown in the upper figure* before forging, and in the lower* with the shape and dimensions which have been given to it during the extension.

This enlargement is produced by supporting the mandrel at both ends, leaving the hoop without any bottom support during the forging, which operation gradually increases the diameter and reduces the thickness of the walls without materially increasing its length.

The forgings being finished, they are then taken to the machine shop, where, in lathes illustrated by the following views,* they are rough-turned and bored to their rough dimensions.

The forging is centred between the adjustable head-

* Lantern view.

stock and the chuck, which is fitted with steel adjustable jaws. As the forging is turned in the lathe the tools fitted to the adjustable tool-holders in their carriages machine it to the required dimensions, the tools being fed and the carriages traversed by suitable power and gearing. The number of tools employed (four in the lathe* before you) depends upon the power of the machine and the methods of the manufacturer.

In boring,* one end of the forging is attached to the chuck and centred in rests, and as the forging revolves, the tool at the end of the boring bar is fed as required.

When rough-bored and turned, the forging is taken to the tempering furnace,* raised to the desired temperature, dipped into that liquid which is considered best to secure the requisite temper, and returned to the machine shop for the taking out of the specimens, the physical tests and appearance of which are to govern the acceptance or rejection of the piece they represent.

Authorities differ as to the value of oil hardening, but universally agree as to the benefits of annealing. Both are necessary to secure a reliable, uniform product. All gun forgings should be carefully annealed in order to bring to a normal condition any molecules or particles which may have been disturbed by unequal cooling or working. Any form of heating furnace can be adapted for this operation, but those especially designed for the use and control of gas are to be preferred.

The specimens used by the Navy Department are of the type and dimensions* here represented, while those for the army are the ones* that you now see before you.

The forgings that go to make up the gun, having been accepted by the inspectors, are sent to the gun factory for assembling and finishing.

The Bethlehem Company has contracted to furnish the War Department with 100 high-power breech-loading guns of eight-inch, ten-inch and twelve-inch calibre, finished complete, and its gun factory is now being rapidly equipped with the special machinery needed for their fabrication.

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* Lantern view.

The interesting view* now before you represents the interior of the principal gun shop of the Washington gun factory. The machines are arranged across the shop and are served by two travelling cranes of twenty-five and 100-ton capacity. The turning and boring lathes* employed for finishing are similar in construction to those used in the rough work, but are not required to be so powerful. In the final machine finishing fewer tools are used.

In the first two machines of the view before you the operation of boring is being performed, the bit being attached to a long, strong bar, which is fed into the revolving tube or hoop.

Peculiarly-shaped bits,* called "packed-bits" and "hog-bits," are employed for this work.

The next operation, after the parts are reduced to their finished sizes, is the assemblage. In this view* we have the tube and jacket represented before assemblage, while the lower figure* represents the parts as assembled.

The operation of jacketing a gun is shown in the two following views.* The tube is secured in a vertical position in a large pit, and the jacket, raised to its shrinkage temperature in a hot-air furnace, is lifted from the furnace by the travelling crane and lowered to its proper place upon its tube. Water circulating through the interior of the tube and sprayed upon the lower end of the jacket governs the cooling to secure the proper shrinkage.

The view* before you now is a very interesting one, showing jackets for the four, five, six, eight, ten and twelve-inch navy guns, ready for insertion in the heating furnace for shrinkage upon their respective tubes.

The hoops are shrunk on in a similar way, although much of this work in some factories is done in the lathe, the gun being then in a horizontal position.

The effective power of shrinkage is well illustrated in the accompanying view, *Fig. 1*, a reproduction of an experiment made many years ago at Sir Joseph Whitworth's works in England, to show its effect and value.

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* Lantern view.

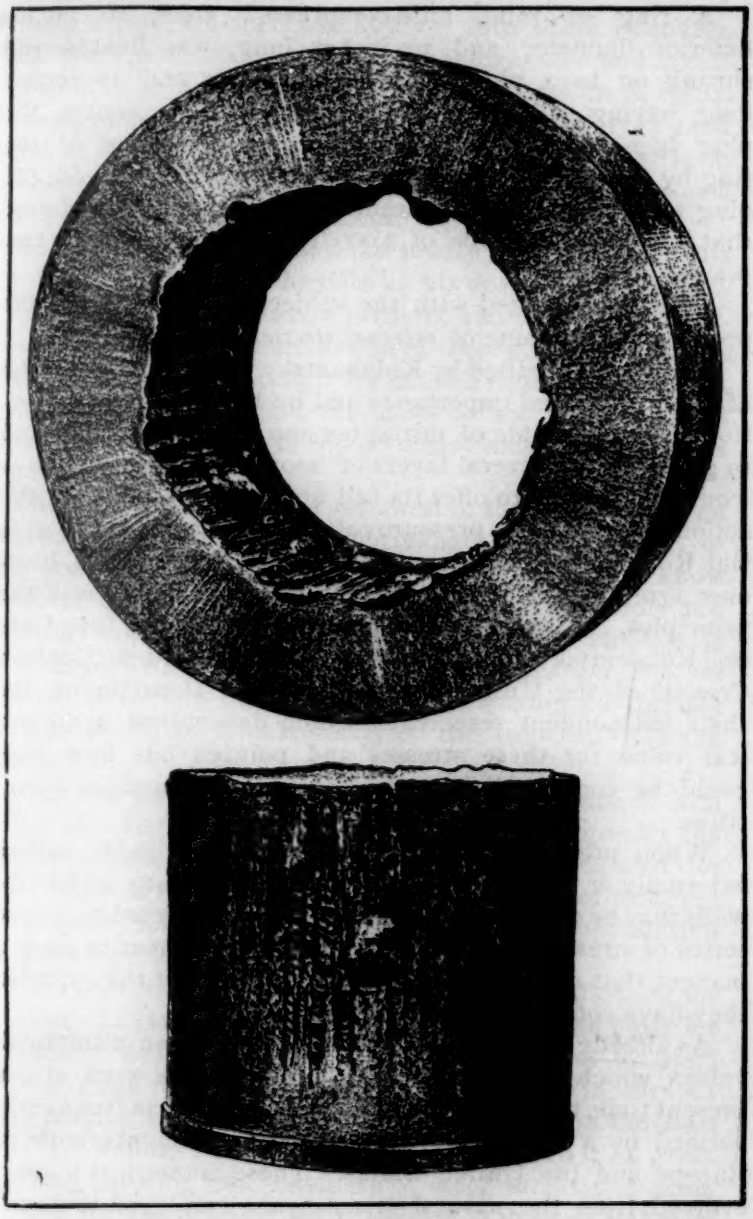

FIG. 1.—Sir Joseph Whitworth's experiment showing the effect of shrinkage.

A ring of mild, fluid-compressed steel, 30 inches exterior diameter and 30 inches long, was heated and shrunk on to a plug 18 inches diameter and 16 inches long, having a 6-inch hole bored through its centre, the plug being turned up larger than the diameter of the ring by the proper shrinkage allowance. When cold, the plug was forced out by dydraulic pressure and it was found that it required a force of 3,000 tons to separate the two pieces.

Directly connected with the subject of shrinkage is the problem of the value of *internal stresses.*

Rodman is credited by Kalakoutsky with the explanation of their cause and importance and by Birnie for the exposition of the principle of initial tension in hooped guns, and to giving to the several layers of hoops such a shrinkage as would cause each to offer its full strength in resisting the action of an interior pressure calculated to rupture the gun. But Rodman applied them only in the foundry. Both, however agree that we are indebted to Lame for the *origin* of the principles. Further, we owe many thanks to the late General Kalakoutsky, of the Russian Artillery, and to Captain Crozier, of the United States Ordnance Department, for their independent researches, which determined a numerical value for these stresses and pointed out how they could be converted from injurious into beneficial quantities.

When pressure is applied to a hollow cylinder, either externally or internally, the interior layers into which its walls may be conceived to be divided are subjected to a new series of stresses, which combine with the former in such a manner that at every point of the thickness of the cylinder they have common resultants.

As already stated, these have all been given numerical values which are employed in all shrinkage work at the present time, their theoretical values having been frequently verified by a very large number of experiments both in Europe and the United States. These numerical values, evolved from the natural stresses, are employed to determine the magnitude of the stresses of built-up cylinders,

stresses which are mechanically put into these cylinders, when formed of materials of such thicknesses and condition as may be assumed to be practically free from initial stresses, or combined with the initial stresses (if they exist in any of the parts), or with the stresses which may arise in the course of manufacture. Useful stresses are developed and construction regulated accordingly.

General Kalakoutsky devoted nearly twenty years of his life, from 1871 to 1889, the date of his death, to the consideration of these important questions, and to the determination of the law of the distribution of these stresses under the conditions of manufacture. He defined internal stresses as those which exist within the mass of any body when it appears to be in a state of repose or not under the influence of external forces.

The formulæ and tables followed in the regulation and preparation of the required shrinkages are the result of long years of research, study and experiment, and I know of no treatise on the subject which defines so simply and definitely the injuries and benefits of internal stresses as a work published in 1888, entitled *Investigations into the Internal Stresses in Cast Iron and Steel*, written by the late General Nicholas Kalakoutsky, of the Imperial Russian Artillery.

I had the pleasure of knowing and seeing much of him during the last part of his life, and enjoyed greatly the opportunities which my intercourse with him secured for me; I had the further satisfaction and pleasure of bringing Kalakoutsky and Crozier to a more intimate appreciation and knowlege of what each was accomplishing.

The reports of the official investigations to determine for the army the class and quality of material and the basis for shrinkages to be employed in the construction of steel built-up guns are very attractively summarized in Birnie's "Gun-making in the United States," published in the *Journal of the Military Service Institution*, in 1891. In it he gives diagrams showing the elasticity of steel, sections of parts prepared for assemblage, their position at various stages of

assemblage, the various compressions, and the use and modifications of Clavarino's formulæ.

Birnie found in his hoop shrinkage experiments that the degree of accuracy obtained was ninety-eight per cent. of the anticipated mathematical results, which, together with other results he acquired, fully justifies the claim that the production of the proper degree of tensions in a built-up gun is a certain process.

A long list of experiments has not only supplied us with a vast amount of valuable mechanical and metallurgical data, but has given us additional assurance of the strength and endurance of the built-up forged steel gun, as far as the material and construction are concerned.

There is another question, however, in connection with gun construction, which has not yet been satisfactorily solved, a solution of which may not be so easily attained; that is, how to prevent the erosion of the bore by powder products. This wearing of the barrel is at the present time a cause of the greatest anxiety to ordnance engineers and gun makers. Its disastrous effects* in ordnance where such enormous powder charges are employed have no doubt greatly influenced some artillerists against the largest calibres, whose racking and smashing powers must be employed to destroy the heaviest armor.

If we do not change the propelling agent I believe we must look to the amount of work put upon the metal and its treatment rather than to the chemistry alone of the metal for the determining agents that will prevent or reduce the amount of erosion; and that the solution of the problem will be found in the mechanical field. This difficulty will probably be best surmounted by carbonizing the bore, which should be highly polished or hardened by mechanical mandrelling, in order to secure the smoothness needed to prevent scoring by powder products. The employment, therefore, of any alloy or of any mechanical work that will aid in securing this highly hardened smoothness, without reducing the requisite elastic strength, will greatly

* Lantern view.

assist the solution of this difficult problem. These results cannot be obtained, however, by any sacrifice of attention to the chemistry of gun steel.

If erosion is mainly due to the chemical action of the powder gases and deposits that some powders leave the powder maker, by changing the mechanical or chemical composition of his products or substituting some other propelling agent, may pass the mechanic in his search for the means of rendering his gun barrel impervious to the destructive action of powder just as the manufacturers of slow-burning powder outstripped the designers of accelerating guns in securing high velocities.

If we accept the new powders we may have to sacrifice the excellent ballistic results that the erosive powders have given, but if the mechanic succeeds, any kind of powder can probably be used.

If erosion is due to high pressures and temperatures the use of the stronger powders would increase erosion in the proposed short guns; but if it is due to the mechanical work of the non-gaseous (liquid and solid) residue, these new powders, if they can be made reliable, will be a boon.

The shrinkage tables at present used by the two gun factories in their fabrication of built-up guns were, I believe, prepared by Lieutenant Commander Dayton and Professor Alger, of the Navy, and by Captains Birnie and Crozier, of the Army.

After the final finish-turning* and boring* has been accomplished the gun is chambered,* the chamber being of a diameter greater than that of the bore, and the gun is put into the rifling machine* to be rifled. The rifling head is fitted as here* represented, and the rifling is effected usually during the withdrawal of the head by the bar to which it is attached. The number of cutters on the rifling head varies in different machines and the pitch of the rifling is governed by the guide bar as represented in this view* or by gearing.

The threading* and slotting* are done by what is usually

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* Lantern view.

called a threading and slotting machine,* which carries a tool in an adjustable holder that screws the thread or is employed as a slotter to remove those segments of the thread which allow the entrance of the interrupted screw of the breech plug, the gun being carefully centred in centring rests.

This view* shows on a larger scale the operation of cutting the slot ways.

The breech plug, with its mushroom or other gas check, and the various devices for opening, closing, latching and firing, are then fitted, the gun is sighted and carefully examined, and we have the finished gun.*

The present view* represents a twelve-inch navy gun fitted to a proof carriage, showing the method of securing it to the slides, its breech mechanism open and a telescopic ram for loading attached to the carriage.

As there are still a few believers in muzzle loading it may be well to recall the advantages of breech loading: It permits the projectile to be of the greatest possible diameter, secures accuracy of fit, and affords the best means for the application of the expanding material to take the rifling. Any sparks remaining in the bore can be easily and surely removed, thereby preventing a not unusual source of danger. Any injury to the vent can be readily repaired in the movable breech-piece. The gun can be more rapidly fired, and the fouling of the bore does not interfere with the loading. There is no danger of double shotting. The bore can be more readily inspected and any weakness more easily discovered. And, above all, breech-loading permits increased length of guns for use on board ship, and provides greater protection for the gunners.

[*To be continued.*]

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* Lantern view.

THE SPECIFIC HEATS OF THE METALS.

BY JOS. W. RICHARDS, PH.D.,
Instructor in Metallurgy, etc., in Lehigh University.

[*A lecture delivered before the Franklin Institute, January 30, 1893.*]

The lecturer was introduced by the Secretary of the Institute and spoke as follows:

MEMBERS OF THE INSTITUTE, LADIES AND GENTLEMEN:

For the purpose of showing clearly the field to be covered, I will refer at once to five heads under which the subject will be considered:

(1) Definitions. The range of the subject.
(2) Methods.
(3) Historical Treatment. The investigators; work done by each.
(4) Discussion of the results. Tables, diagrams, formulæ.
(5) Theoretical Treatment. Discussion from the chemical and mechanical standpoints.

I.

The specific heat of a body is the ratio between the amount of heat necessary to increase its temperature 1°, and the amount necessary to increase the temperature of an equal weight of water 1°.

Being a *ratio*, it is of course independent of the weights of the substance and water taken, or of the kind of thermometric scale employed, but in order to introduce regularity into these comparisons the weights taken are a kilogramme or a pound, and the degree either Centigrade or Fahrenheit. Throughout this lecture I shall use the metric unit of weight and the Centigrade scale.

Since the observations on so many substances are to be compared with water as a standard, it will be well to

examine our standard carefully, to see if it is invariable. We find that *pure* water is absolutely the same substance at all times, so that no variation can arise from there being two kinds of water; but, examination reveals the fact that the amount of heat required to raise the temperature of a kilo of water 1° is a different amount at different temperatures. For instance, it takes more heat to heat a kilo of water from 90° to 91° than from 1° to 2°. Scientists have investigated this matter for fifty years, and it is only quite recently that reliable figures have been obtained showing just to what extent, quantitatively, the specific heat of water varies with the temperature. The French scientist, Regnault, had found a gradual increase from the freezing point up, and for this reason the water unit was chosen as the amount of heat required to raise a kilo of water from 0° to 1°; but since these observations of Regnault have been proven incorrect, the general conclusion now is that the water unit should be considered at from 15° to 16°, at which point the specific heat of water appears to reach a minimum value.

I have just explained how the specific heat of water varies with the temperature at which it is taken. This is also true of all other bodies, so that a complete investigation of the specific heat of any substance would mean the determination of that property at all attainable temperatures, from the lowest to the highest. In the course of such an investigation the substance would in many cases pass from solid to liquid and then to gas, and it would be found to possess different specific heats in these different states. Furthermore, in passing from solid to liquid, or from liquid to gas, it would be observed that a large amount of heat is absorbed without any increase of temperature at all. At these points we say that heat is rendered latent in the body. The complete calorific investigation of a body should therefore include the fixing of the temperatures at which such sudden absorptions of heat occur, and the amounts of heat rendered latent.

A new name has thus attached itself to this branch of experimental physics; we now speak of undertaking the "calorific investigation of a substance" in place of the mere

determination of its specific heat at ordinary temperatures.

While this subject is properly a branch of physics, we shall see more clearly further on that it treads very close to the foundation ground of chemistry, throwing a side light on many of the conceptions of that science, and tending in many ways to give us chemical theories on a purely mechanical basis.

II.

Referring to the experimental methods employed in these investigations, we may class them under two heads:

(1) The method of cooling.

(2) Calorimetric methods.

The first method may be briefly described as follows: The substance is made hot, and then placed in a close vessel kept at a constant temperature by a stream of water, and the rate at which it cools is carefully observed. A delicate thermometer embedded in the substance is read every five or ten seconds and the curve of cooling is carefully plotted. Since the conditions are such that the amount of heat radiated per second depends only on the temperature of the substance, it follows that the rate at which it will cool will depend directly on the amount of heat stored up in the body, or upon its calorific capacity. Thus, different substances can be investigated and compared, but it will be readily seen that the method gives only comparative results, and in order to get absolute values we must take some one substance whose specific heat has been otherwise determined as a standard, and then the values for the other substances can be calculated.

This method was first used by J. T. Mayer, in 1808, and afterwards greatly improved by Dulong and Petit, but the results obtained by it are not considered as accurate as those given by some other methods, and it is not now used to any extent. The complicated formulæ for cooling, which must be used, and the great care required to obtain good results have also helped to bring the method into disuse.

Under the second head, calorimetric methods, we include all those methods in which the heat capacity of a body is

directly measured. This may be accomplished in three ways:

(1) The method of mixtures.

(2) The ice calorimeter.

(3) The steam calorimeter.

The method of mixtures consists simply in heating up the substance to an accurately-determined temperature, and then immersing it suddenly in a known weight of water, or of any fluid whose specific heat is accurately known. From the temperature of the mixture, and the known specific heat of the liquid, the unknown specific heat of the substance under investigation, or rather the amount of heat given out by it in falling from the high temperature to the temperature of the mixture, becomes known. Of course, in determining the true temperature of the mixture it is necessary to make corrections for heat absorbed by the vessel in which the mixture takes place, etc., but this line would lead to a discussion of calorimetric methods which would be outside the scope of this lecture. But, aside from this difficulty, this method has other defects. One of these is the difficulty of accurately determining the temperature of the substance as it was dropped into the calorimeter. Even supposing that its temperature while in the air bath or furnace is accurately determined (a difficult matter for high temperatures) there is a certain fall in temperature during the transfer into the calorimeter, an amount which increases very rapidly with high temperatures. Another defect sometimes mentioned is loss of heat by vaporization of the water, but this is so small as to be in most cases negligible. The most serious of these defects, the first, has been remedied by the use of the "double method of mixtures," which consists in using two calorimeters and a platinum ball along with the substance being investigated. If the substance and the platinum ball are placed in the furnace together, then removed together and dropped simultaneously into the two calorimeters, the amounts of heat given out by each in cooling from the same temperature can be measured, for it can fairly be assumed that the platinum ball is at exactly the same temperature as the other substance at the

moment of immersion. But the specific heat of platinum has been investigated with the greatest care, and so from the amount of heat it has given out to the calorimeter we can calculate its temperature at the moment of immersion. In this way the most serious defect of the method of mixtures has been overcome, especially when working at high temperatures. Your lecturer has done considerable work by this double method, with very satisfactory results.

The ice calorimeter measures the heat given out by the substance in cooling to zero, by the weight of ice which it melts. Knowing just how much heat is absorbed by one gramme of ice in becoming water, it is necessary only to weigh the amount of water formed to get the heat given up. This calorimeter was first devised and used by Lavoisier and Laplace, and has been greatly improved by Bunsen. As a measurer of heat, its principal defect was that all the water produced could not be collected and weighed. Bunsen's improvements largely overcame this error. The other defects incident to its use were principally the loss of heat during transfer to the calorimeter, which can be overcome by the "double method" already explained. All determinations made in this calorimeter depend on the value of the latent heat of water, which is, however, known to a high degree of accuracy.

The steam calorimeter measures the amount of heat absorbed by a body in being heated up to 100°, by the amount of steam which it condenses in doing so. For this purpose, the substance at an accurately known temperature is suddenly plunged into a current of dry steam. The weight of water finally collecting on it is determined, and the heat absorbed by the body is the product of this into the latent heat of steam. Like the ice calorimeter, all determinations made in this way depend on this constant, the latent heat. More serious errors, however, are caused by the condensed water falling off the body, and by some of it being carried away mechanically by the steam. Also, since the latent heat of steam is very large, a small error in weighing the water condensed will make a large error in the result. No very exact figures can be expected from this method of investigation.

Before closing this description of methods, I might here remark that the latent heat of fusion, a very interesting phenomenon when speaking of the metals, can be determined in several ways. Assuming the melting point known, we can calculate from the observed variation of the specific heat in the molten state, how much heat the *molten* substance would contain at the melting point; we can in a similar way calculate how much heat the *solid* metal contains at that temperature; the difference between these two quantities will be the latent heat of fusion. Or, we may determine the first quantity directly, by taking a large quantity of molten metal and letting it cool gradually to the setting point. When part is already set, the part which is still fluid, and whose temperature is exactly the melting point, is poured out directly into a calorimeter, and the amount of heat in it is thus measured directly. The second quantity may also be determined directly, by taking a bath of molten metal, letting part set, and then plunging a little spiral of wire of the same metal into the still-fluid part. The heating up of the wire chills a certain quantity of metal into the solid state, at this temperature, and the little lump thus formed is dropped into a calorimeter. Or, the latent heat of fusion can be determined by the method of cooling; for the temperature of the metal remains constant, while the metal is setting, and from the time which it takes to set, compared with the rate at which the liquid and solid metal cools before and after the setting, the amount of heat evolved during setting can be computed. For this, however, we need to know the value of the specific heat of the metal somewhere in the neighborhood of its setting point.

III.

Historically considered, we may begin by saying that about 1750 it was universally supposed that there was little or no difference in the heat capacity of different kinds of substances, and it was further supposed that solids were converted into liquids by the addition of an insignificant amount of heat when they had once been raised to the melting point.

Dr. Black, of Edinburgh, was the first to announce correct ideas on these subjects. In his chemical lectures at Glasgow, between 1760 and 1765, he pointed out the great differences in the heat capacities of different substances, and made experiments in his lectures demonstrating the great amount of heat absorbed during the fusion of ice and the vaporization of water. He determined the latent heat of water to be 140° F. units, equal to 77°·8 C. units. A very able assistant of his, Dr. Irvine, made further investigations between 1765 and 1770, and determined the latent heat of fusion of tin, which he called 500°. By this he meant that the heat given out by tin in setting would be sufficient to raise the temperature of 500 times its weight of solid tin 1°, or an equal weight of solid tin 500°. These being Fahrenheit degrees would be equal to 277°·7 C. These we might call tin units, and to convert them into the ordinary water units we should have to divide them by the ratio of the specific heat of water to the specific heat of solid tin at its melting point. The figure thus reached is not far from that obtained by later observers.

Dr. Crawford was another colleague of Dr. Black, and published in his *Treatise on Heat* the results of many experiments on specific heats. It was said of him, thirty years later: "To this ingenious experimenter we owe some of the most remarkable facts respecting specific heat yet known." He investigated the specific heats of antimony, copper, iron, lead, mercury, tin and zinc.

Dr. Black called this newly investigated property of bodies "*capacity for heat*," but before the publication of his and his colleague's results, which was delayed by Dr. Black's great modesty, Professor Wilcke, of Stockholm, who had been working out similar ideas, published the results of some experiments and attached the name "*specific heat*" to this property. Professor Wilcke worked by the method of mixtures, and published values for antimony, bismuth, copper, iron, lead, silver, tin and zinc.

Dr. Kirwan, in England, made similar experiments, to obtain values for the specific heats of antimony, gold, iron, lead, mercury and tin.

Lavoisier and Laplace made experiments with their ice calorimeter. The only one of the metals which they seem to have investigated was mercury. We owe to Lavoisier the expression "*latent heat of fusion*," and we find in his writings a wonderfully clear conception of what specific heat really includes, how it increases with temperature and to a different amount in different substances. So clear were his views that an enthusiastic Frenchman exclaimed, in 1886: "All work on specific heats since his time has been done on the lines laid down by Lavoisier."

J. T. Mayer, Leslie and Dalton worked by the method of cooling, but only the latter gives results for the metals, and these appear to be very rough approximations. The method was afterwards greatly improved by Dulong and Petit. Count Rumford and Avogadro can also be included in the list of experimenters in this line, but their results, especially those of Avogadro, were little trustworthy.

Dr. Wm. Irvine, son of Dr. Black's one-time assistant, repeated and extended some of his father's experiments. He determined the latent heat of fusion of bismuth, lead, tin and zinc.

Rudberg, in 1830, determined the latent heat of fusion of lead and tin by the method of cooling.

Erman made similar experiments in 1830, but the discordance of his results shows that his apparatus was not properly constructed or managed.

F. E. Neuman determined in 1831 the specific heats of antimony, bismuth and zinc by the method of cooling. De la Rive and Marcet investigated cadmium, cobalt and molybdenum, by the same method.

Dulong and Petit were the first investigators to make any systematic study of the variation of specific heat with the temperature. They determined the specific heat of antimony, copper, iron, mercury, platinum, silver and zinc, at various temperatures up to 350° C. Their method was that of mixtures. They also determined the specific heats of antimony, bismuth, copper, gold, iron, lead, platinum, silver, tin and zinc at ordinary temperatures by the method of cooling. These scientists were the first to remark that

the specific heats of the elements are inversely proportional to their atomic weights; a law which while not rigidly exact, yet is so nearly true that the slight deviations from it may fairly be ascribed to other causes yet to be investigated. In fact, it will be seen further on, in discussing the theory of specific heat, that this law may be directly deduced from the modern mechanical theory of heat.

Bède in 1855, Byström in 1860, and Naccari in 1877, have made series of experiments in exactly the same manner as Dulong and Petit's first set by the method of mixtures, at temperatures between 100° and 300°. Bède examined antimony, bismuth, copper, iron, lead, tin and zinc; Byström, iron, platinum and siver; Naccari, aluminum, antimony, cadmium, copper, iron, lead, nickel, silver and zinc.

In 1836, Pouillet made a very careful study of platinum, using an air thermometer for recording temperatures and extending his determinations up to 1,200° C. He worked with great care, and his results would have been excellent had it not been that a defect in his air thermometer introduced an error of 30° or 40° in his determinations of very high temperatures, and thereby vitiated his results.

A classical set of experiments was made by Regnault by the method of mixtures. Commencing with 1840, he worked for several years in this field, giving us values which are usually regarded as standards. However, whenever he used metals not quite pure for his experiments, he gave figures which have since been revised. He used a steam bath for his upper temperature, so that his figures are really the mean specific heats between 10° or 15° and 98° or 99°, or the true specific heats in the neighborhood of 55° to 60°. He investigated twenty-seven of the metals, as follows: Aluminum, antimony, bismuth, cadmium, cobalt, copper, gold, iron, iridium, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, osmium, palladium, platinum, potassium, rhodium, silver, sodium, thallium, tin, tungsten and zinc.

Dr. Kopp was a laborious investigator of specific heats. He determined those of many metals and of a host of chemical compounds. He used the method of mixtures, but he

seems to have worked with unusually small weights of the substances, and from this cause or some others inherent in his apparatus his results on the same substance often varied among themselves five per cent., and occasionally even ten per cent. In all such cases he figures up the average value of all his determinations. Regnault's results for one substance seldom varied over one per cent. from each other, so that wherever Kopp's values vary from Regnault's, the latter's deserve the preference. Kopp obtained the mean specific heats between 10° or 20° and 60° or 70°, or the true specific heat at about 35° to 40°. He investigated aluminum, antimony, bismuth, chromium, copper, cadmium, lead, magnesium, platinum, silver, tin and zinc.

Professor Bunsen used his modification of the ice calorimeter for determining the mean specific heats of antimony, calcium, cadmium, indium, ruthenium, silver, tin and zinc, between 0° and 100°, or the true specific heats at about 50° to 55°.

Professor Mallet determined the specific heat of chemically pure aluminum (used in investigating its atomic weight) between 0° and 100° with Bunsen's ice calorimeter.

Person used Regnault's apparatus and the method of mixtures to determine the specific heats of bismuth, cadmium, lead, tin and zinc in the solid and liquid states, from which data he calculated their latent heat of fusion. He also determined the latent heat of fusion of cadmium, silver and mercury by the method of cooling.

Dr. W. F. Hillebrand, in 1876, determined the specific heats of cerium, lanthanum and didymium by the Bunsen ice calorimeter.

T. S. Humpidge determined the specific heat of beryllium in 1885.

L. Pebal and H. Jahn investigated antimony between $-76°$ and $+33°$.

Zimmerman and Bluncke both determined the specific heat of uranium.

Nilson and Pettersson investigated germanium and titanium.

Milthaler investigated mercury at different temperatures and derived a formula for the variation of its specific heat with the temperature. Naccari went over the same ground for temperatures between 0° and 250°.

Kunt and Warburg investigated the specific heat of mercury vapor. E. Reynolds determined the specific heat of beryllium and Mixter and Dana that of zirconium.

Weinhold investigated platinum at high emperatures, using the air pyrometer, but his results are discordant, showing imperfections in his method, so that his results did not supersede those of Pouillet.

More recently, J. Violle made a study of platinum up to 1,200° C., using the method of mixtures, an air pyrometer and every refinement possible to ensure accuracy. His determinations are the best we have for this metal, and serve as the basis for calculating the temperature of the ball at the moment of immersion when working by the double method. Violle used platinum in this way for determining the specific heats of gold, iridium and palladium up to 1,200°. He also found the latent heat of fusion of platinum and palladium by determining the amounts of heat in the molten metal and in that just set.

Le Verrier (*Conservatoire des Arts et Metiers*) has recently investigated aluminum, copper, lead, silver, tin and zinc by the method of mixtures, using the recently-devised Le Chatelier pyrometer to determine temperatures, which it is stated can be done at the very moment of the immersion of the metal in the water of the calorimeter. He finds sharp variations in the specific heats of most of these metals, which no other investigator has seen any indications of, so that his results are very much doubted. Careful and very concordant experiments made by your lecturer on copper, by the double method, have failed to show any indications of variations at points indicated by Le Verrier, so that we must put on Le Verrier the burden of proving his results by repeating his experiments and giving all their details; in short, he must prove his position by further proofs before his results will be seriously considered as true.

Pionchon has done perhaps the most accurate work of

recent years in his studies of cobalt, iron, nickel, silver and tin (1886), and aluminum (1892). He worked by the double method of mixtures, using Violle's formula for calculating the temperature of the platinum. His results are very concordant except in the case of aluminum below 300°, where a variation of five per cent. between his formula and the experimental results would be possible. Otherwise, he has given complete curves for the specific heats of aluminum, cobalt, iron, nickel and silver to 1,200°, and tin to 1,000°, and determined the latent heats of fusion of aluminum, silver and tin.

An exactly similar set of experiments was made by your lecturer on aluminum, up to 600°, with a determination of its latent heat of fusion. In connection with Prof. B. W. Frazier, of our University, a similar set of experiments is now in progress with copper, the result of which will give the curve for its specific heat to the melting point, its latent heat of fusion and the specific heat of molten copper. The approximate values so far found are given in discussing copper. The calorimeters and apparatus used by Professor Frazier and myself are shown in the accompanying cuts. *Fig. 1* shows a section of the calorimeter. The outer box is walnut, the calorimeter proper is of thin brass, tightly covered, and packed in with cotton. The stirrer is of wire mesh, fitting closely to the walls, and provided with a glass rod for a handle. (Wooden rods warped and worked stiffly.) The thermometers are standard Baudin, graduated to 0°·02 and easily read with a lens to 0°·0025. The calorimeter is charged with about 300 grammes of water, and, using a platinum ball of fifty-two grammes, the rise in temperature is approximately 0°·5 for every 100° fall of the platinum ball. The corrections for losses of heat to the calorimeter during the experiment are made by a system worked out by us, which gives most satisfactory results, but which cannot be described in the limits of this lecture. Suffice it to say that the probable errors in the calorimeters themselves are within 0·1 per cent.

Fig. 2 shows the apparatus for containing the metals in the furnace. It is a piece of fire-brick, cut as indicated, and

with two smooth French annealing cups fastened into the holes. In operation, the platinum is put in one side, the other metal in the other, and the crucibles covered by porcelain lids connected by a stout platinum wire. The whole is then heated several hours at the desired temperature. Everything being ready, the two calorimeters are brought into the furnace room, and opened to receive the balls. The brick is withdrawn from the furnace, the lids are lifted off by the platinum wire. Then by inclining the brick between 45° and 90° first to one side and then to the other, the two balls are dropped one at a time, into their respective calorimeters. The stoppers are replaced, the calorimeters are carried to their room and readings are taken for five minutes. In order to avoid errors, a full experiment is made to consist of two separate ones made as nearly as possible at the same temperature, but with every condition reversed, which could affect the result; viz:

(1) The position in the furnace.

(2) The position in the brick.

(3) The order of dropping out of the brick.

(4) The calorimeter into which it is dropped.

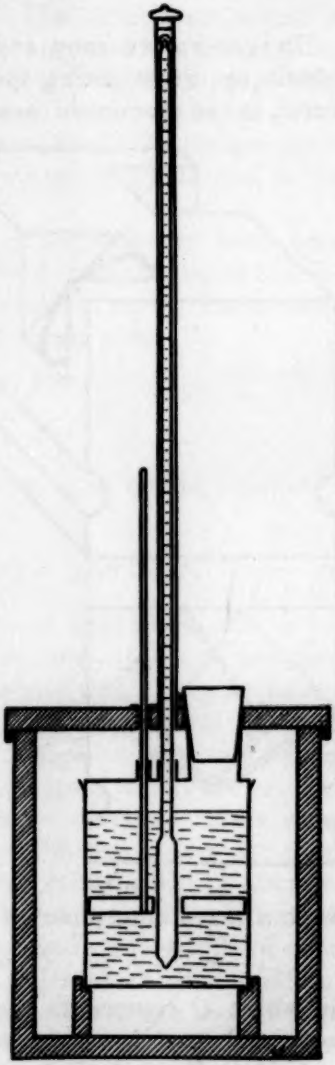

FIG. 1.

With these precautions, we have not rested satisfied until we have reduced the maximum difference between

corresponding experiments to *less* than one per cent., and the deviation from the mean to *less* than 0·5 per cent.

IV.

In general we may say that the only factor we really obtain by investigating specific heats by the method of mixtures, is the amount of heat given out by the substance in cooling through a certain range of temperature. The lower temperature is that of the calorimeter, which usually varies between 15° and 25°, while the upper temperature varies at will. If the results obtained for any one substance are plotted on a diagram, taking the range of temperatures as abscissas and the heat given out as ordinates, it is at once found for most metals that a straight line will not pass through the points. The heat given out increases in greater proportion than the temperature, giving a curve which is convex towards the axis of abscissas, gradually becoming steeper and steeper. The formula for such a curve must then be of this nature:

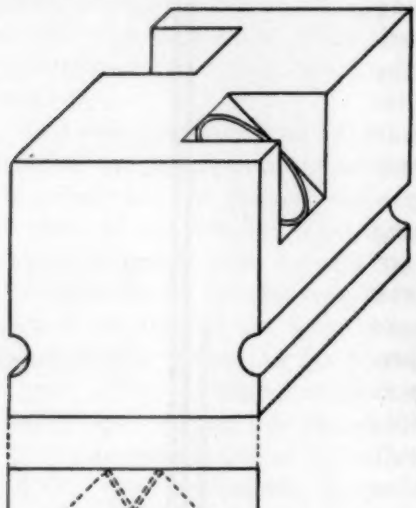

FIG. 2.

$$Q = a\,t + \beta\,t^2 \qquad (1)$$

in which Q represents the quantity of heat given out to zero, and t any temperature. If a curve of this nature does not rise sufficiently fast at high temperatures, a third term can be added, making it

$$Q = a\,t + \beta\,t^2 + \gamma\,t^3$$

It has been found that allowing for errors of experiment formulæ of this kind will fit almost all the observations on specific heats so far made, and in most cases the formula of two terms answers perfectly. The third term seems to be needed only when the curve is approaching the melting point or a critical point of the substance. when part of the heat necessary for a change of state seems to be absorbed before the point itself is actually reached. At temperatures distant from these points only two terms are needed in the formula.

Suppose, now, that a series of experiments have been made with a metal, and it is wished from the data obtained to construct the formula reckoned to zero. For a body cooling from t_2 or t_1 to zero the formula gives

$$Q_1 = a\,t_1 + \beta\,t_1^2$$

$$Q_2 = a\,t_2 + \beta\,t_2^2$$

therefore, for a body cooling from t_1 to t_2, the amount of heat given out must be

$$(Q_1 - Q_2) = a\,(t_1 - t_2) + \beta\,(t_1^2 - t_2^2) \qquad (2)$$

Having measured the quantity of heat given out in the different experiments between various high and low temperatures, the values of $(Q_1 - Q_2)$, t_1 and t_2 can be substituted in equation (2), and thus each experiment gives us some relation between a and β; therefore any two experiments will give us two equations from which the value of these unknown coëfficients may be derived. Two other experiments might give slightly different values for a and β, and thus several slightly varying values could be obtained and their average taken as the true values. A much neater and more accurate way, however, is to substitute in equation (2) the data obtained in each experiment, thus obtaining as many equations of condition as there are experiments made, and from these to calculate the most probable values of a and β by the method of least squares. The formula thus derived will give a curve which will pass through the mean of all the observations made.

If the heat given out by a substance in falling from t to zero be divided by the range of temperature t, the quotient is the mean value of the specific heat between those temperatures, therefore:

$$S_m = \frac{Q}{t} = \frac{\alpha t + \beta t^2}{t} = \alpha + \beta t \qquad (3)$$

Or, if the substance falls from t_1 to t_2 instead of to zero,

$$S_m = \frac{Q_1 - Q_2}{t_1 - t_2} = \frac{\alpha (t - t_2) + \beta (t_1^2 - t_2^2)}{t_1 - t_2} \qquad (4)$$

$$= \alpha + \beta (t_1 + t_2)$$

If we evaluate equation (2) for two temperatures within 1° of each other, we obtain the heat given out for a fall of 1°; that is, the actual or true specific heat at that temperature. A much more elegant method, however, is to take the first differential coëfficient of the equation representing the heat given out in falling to zero [equation (1)], and thus obtain the equation for the *ratio* of the heat given out to the fall in temperature, which ratio is the true specific heat.

Therefore, taking

$$Q = \alpha t + \beta t^2 + \gamma t^3$$

We have

$$S = \frac{dQ}{dt} = \alpha + 2\beta t + 3\gamma t^2$$

Or, leaving out the third term as before,

$$S = \alpha + 2\beta t \qquad (5)$$

This formula is very similar to equation (3) for the mean specific heat, both of them being the formulæ of straight lines, starting when $t = o°$ at the value α, which is therefore the true specific heat of the body at zero. The formula for the true specific heat can thus be easily deduced from that for the amount of heat; and it is this quantity which has an intimate dependence on the properties of the substance

at any given temperature. For this reason, the diagrams which follow show the variations of the *true* specific heat with the temperature.

[There were here thrown upon the screen a number of diagrams, with running comments by the lecturer. It has been thought advisable in printing the lecture to incorporate these diagrams into an Appendix, in which is discussed the specific heat of each of the metals separately at a length which would have been undesirable, and indeed impossible, during the delivery of the lecture.]

[*To be continued.*]

CAUSES OF FIRES.

By C. John Hexamer.

[*Concluded from vol. cxxxv, p. 299.*]

CAUSES OF FIRES IN DWELLINGS.

Statistics on the causality of fires are very meagre. The best general tables we have in this country, are those of the *Chronicle*. Mr. P. A. Montgomery has made a number of interesting calculations from the *Chronicle* tables, published in 1892, his purpose being "to ascertain the relative importance of the *principal* causes of fires, peculiar to certain classes of risks, incendiarism omitted." Exposure fires also were not taken into account. The results reached in regard to *dwellings and tenements* showed the following table of causes of fires:

Chief Causes.	*Relative Percentage of Inherent Physical Hazard.*
Defective flues,	21
Matches,	9
Explosions, lamps,	9
Forest fires,	9
Sparks,	7
Stoves,	6
Gas jets,	3
Lamp accidents,	3

Chief Causes.	*Relative Percentage of Inherent Physical Hazard.*
Explosions, oil stoves,	3
Lightning,	2
Carelessness,	1
Open fireplace,	1
Fireworks,	1
Candle,	1
Accident,	1
Cigar stub,	1
Fire crackers,	1
Stove-pipe,	1
Ashes,	1
Furnaces,	1
Oil stove accident,	1

BOARDING HOUSES.

Defective flues,	18
Explosions, lamps,	16
Gas jets,	9
Matches,	8
Stoves,	7
Cigar stubs,	6
Sparks,	5
Open fireplaces,	3
Lamp accidents,	3
Ashes,	2
Explosions, oil stoves,	2
Carelessness,	1
Stove-pipe,	1
Candle,	1
Fireworks,	1
Furnace,	1
Spontaneous combustion,	1

A table, published in the *American Exchange and Review* (June number, 1892), shows that the number of fires in fifteen years (1876, 1878–1891) in dwelling houses in Massachusetts were 12,814, property loss $8,082,322, and the causes of the 1,213 fires in the year 1891 were reported as follows:

Ashes in wooden vessels,	12
Ashes from pipe and pipe in clothes,	27
Burning off paint,	1
Careless use of matches,	50
Children playing with matches,	101

Cigar stub in wooden spittoons,	5
Clothes near stove,	17
Curtains near gas or candle,	38
Defective chimney,	172
Exposure,	111
Electric wires,	3
Fireworks and fire crackers,	11
Fat boiling over,	2
Fumigating with sulphur,	4
Gas leaking,	4
Explosion of gas,	4
Hot iron on wood,	2
Incendiary,	54
Breaking lamp,	77
Breaking lantern,	3
Explosion of lamp,	50
Explosion of lantern,	1
Explosion of oil stove,	30
Lightning,	6
Mice and matches,	36
Overheated stoves,	50
Overheated steam-pipe,	1
Open funnel hole,	1
Plumbers' fire-pot,	7
Rags in funnel hole,	1
Sparks from chimney,	35
Sparks from locomotive,	12
Sparks from stove and fireplace,	14
Spontaneous ignition of rags,	10
Spontaneous ignition (cause unknown),	9
Soot igniting,	23
Starting fire with oil,'	1
Thawing water pipe,	3
Tar boiling over,	1
Timber built into chimney,	1
Wood-work near stove,	6
Wood-work exposed to gas or candle,	14
Volatile oil (naphtha),	5
Smoking in bed,	9
Slaking lime,	1
Powder explosion,	1
Unknown,	187

In Massachusetts boarding and lodging houses, in the above-mentioned fifteen years, 150 fires occurred with a property loss $155,808.

CAUSES OF TWENTY-THREE FIRES IN 1891.

Defective chimney,	4
Curtain near gas,	2
Careless use of matches,	4
Smoking in bed,	2
Unknown,	5
Exposure,	2
Spontaneous ignition,	2
Overheated stove,	1
Mice and matches,	1

Perhaps it will be of local interest to compare the origins of Philadelphia's ash pile, costing $19,319,202.53 in a decade. The statistics contained in the annual report of the Insurance Patrol are worthy of investigation. In the April number of the *American Exchange and Review*, 1893, the results of the decade 1883–1892 have been compared. In order to reduce statistical quotations to a minimum, we quote now all the parts in this comparison we shall hereafter need.

As an approximation, the value of combustible property in the city of Philadelphia may be placed at $1,200,000,000; amount insured, $800,000,000—more than one-half of the insurance on dwellings and contents.

Fire loss in its aggregation is according to value of property per square foot of ground area under equal conditions, otherwise, of ignition, combustibility and fire extinguishment. In other words, loss is according to concentration of value. Philadelphia, like other modern cities, tends to concentrate values. Measured by decades, the fire history of the city shows from about $500 loss per fire to about $3,000 loss per fire. The data of three decades are as follows:

Decades.	*Total Fires.*	*Loss per Fire.*
1856–65,	3,679	$1,772
1866–75,	6,154	3,041
1883–92,	10,801	1,788

(In the decade 1866–75, a period of great manufacturing development, the conflagrative force of the city was at the highest point it has ever attained.)

From 1856 to 1892 the population doubled and combustible value trebled, but the city was burning at about the

same rate of combustion at the end as at the beginning of this period—notwithstanding growth of concentration with augmenting aggregation; an evidence of effective fire extinguishment and fire salvage.

The Patrol report enumerates the 1,410 fires in 1892 as burning $1,684 per fire. Increase in rate of ignition is notable. There were 114 more fires in 1892 than in 1891, with eighty-four more fires in dwelling-houses and fifty-one more fires in stores. The 1,278 fires of 1891 assailed $1,555,664 more insurance than the 1,410 fires of 1892, and the loss of 1892 was $298,901 less than that of 1891. The saving in fire cost in 1892 was due to stores and warehouses, which burned $540,979 less in 1892 than in 1891; woollen goods in 1891 burned more than double all the store and warehouse fires in 1892.

If we take the increase of Philadelphia combustible value from 1883 to 1892 as forty per cent., the $1,172,732 of fire loss in 1883 would have as its equivalent in 1892, $1,641,824, but

	Fires.	*Loss per Fire.*
1883, ...	853	$1,374
1892, ...	1,410	1,684

With 853 fires in 1883, the equivalent ignition in 1892 would have been 1,194 fires, and the excess of $735,639 in proportionate loss in 1892 was largely due to excess of ignitions. But in 1883, the combustive force was about one-half of that of 1884.

We cite the following annual comparisons of the decade, given in the Patrol report:

Years.	*Fires and Alarms.*	*Insurances.*	*Losses.*	*Per Cent.*
1883, ...	853	$8,054,985 00	$1,172,731 75	13·87
1884, ...	897	8,193,526 36	2,254,412 66	27·63
1885, ...	1,078	10,125,704 66	1,755,575 46	17·33
1886, ...	1,153	13,209,584 00	2,717,444 74	20·57
1887, ...	1,041	8,727,679 00	1,253,492 94	11·84
1888, ...	763	9,519,334 39	2,128,136 58	22·35
1889, ...	954	13,855,616 33	1,570,528 61	11·34
1890, ...	1,341	16,222,981 77	1,442,943 09	8·89
1891, ...	1,296	20,689,271 65	2,676,363 87	12·93
1892, ...	1,425	19,133,628 32	2,377,462 83	12·36
		$127,652,301 48	$19,319,202 53	15·11

The annual reports for the last three years of President Wagner, of the Philadelphia Patrol, present the following recapitulations:

BUILDINGS AND CONTENTS.

	1890.	*1891.*	*1892.*
Stores and Warehouses:			
Number of fires,	336	239	290
Insurance loss,	$218,186	$655,790	$114,801
Textile Works:			
Number of fires,	64	69	78
Insurance loss,	$404,322	$1,238,009	$1,191,432
Metal Works:			
Number of fires,	26	40	37
Insurance loss,	$1,429	$68,851	$63,904
Wood Works:			
Number of fires,	44	48	49
Insurance loss,	$385,075	$45,477	$168,456
Printers and Bookbinders:			
Number of fires,	1	13	9
Insurance loss,	$35,040	$209,836	$121,744
Dwellings:			
Number of fires,	543	485	569
Insurance loss,	$34,942	$29,313	$56,005
Stables and Barns:			
Number of fires,	60	59	60
Insurance loss,	$39,044	$52,000	$15,663
Churches:			
Number of fires,	9	3	6
Insurance loss,	$3,694	$12,169	$14,861
Miscellaneous:			
Number of fires,	222	331	312
Insurance loss,	$321,210	$344,898	$630,596

CAUSES OF FIRE IN PHILADELPHIA IN 1892.

Statement showing the causes of fires, number of fires from each, and the losses resulting therefrom:

Causes.	*No. of Fires.*	*Insurance.*	*Insurance Loss.*
Boilers,	13	$391,756 00	$6,271 76
Boiling over of fat, oils, etc.,	25	125,200 00	4,772 81
Bonfires,	11	9,900 00	2,433 00
Candles,	41	821,800 00	118,294 30
Defective flues,	128	668,700 00	12,103 35
Dry rooms,	5	139,200 00	55,967 64

Causes.	*No. of Fires.*	*Insurance.*	*Insurance Loss.*
Electric light wires,	17	$238,400 00	$16,597 44
Fire-pots (tinners'),	5	408,400 00	17,790 51
Fireworks,	36	241,100 00	2,736 68
Friction,	13	710,100 00	100,872 90
Gas jets,	71	2,105,199 00	300,330 14
Heaters,	23	244,080 00	5,756 65
Hot ashes,	19	93,800 00	3,601 16
Kilns,	3	583,500 00	131,224 53
Lightning,	5	443,000 00	10,043 41
Low-down grates,	5	24,000 00	689 00
Matches,	93	545,100 00	9,120 02
Oily rags,	5	138,500 00	6,162 35
Ovens,	8	51,300 00	566 00
Pickers,	24	623,700 00	5,289 24
Ranges,	19	55,500 00	1,262 45
Roasters,	3	79,700 00	2,161 88
Roofers' wagon,	1	25,250 00	5,464 99
Rubbish,	46	871,200 00	10,188 12
Smoking,	16	64,406 66	10,647 64
Sparks from emery wheel,	1	61,500 00	7,907 64
grinder,	1	9,500 00	2,995 80
locomotive,	23	132,100 00	20,156 42
Spontaneous combustion,	26	588,700 00	227,802 38
Stoves, cook and parlor,	93	310,275 00	22,818 96
Stove-pipes,	12	28,200 00	1,589 02
Supposed incendiary	12	18,000 00	2,064 28
Suspicious,	10	217,900 00	43,116 27
Unknown,	230	4,339,556 66	1,148,634 21
Sundry causes, losses of which do not reach $500,	126	2,425,820 00	2,337 05
Total,	1,169	$18,033,143 32	$2,319,770 00
Petroleum Fires:			
Explosions of benzine,	9	$46,800 00	$5,193 15
coal oil,	5	12,250 00	355 75
gasoline,	6	17,450 00	523 25
naphtha,	1	51,400 00	200 00
Lamps, coal oil,	146	746,560 00	44,690 12
gasoline,	12	34,000 00	491 60
Overheated oil tank,	1	76,900 00	2,002 66
Stoves, coal oil,	21	40,325 00	1,901 85
gasoline,	40	74,800 00	2,333 45
	241	$1,100,485 00	$57,692 83
Total,	1410	$19,133,628 32	$2,377,462 83

We will now turn from bare figures to a more general description of the origins of fires in dwellings. One of the most prolific causes of fires is incendiarism. This is of two sorts, (1) by dishonest policy holders, and (2) by acts of revenge and pyromania, which I believe to be a variety of mental disease as prevalent as klopemania. There has been much debate on the amount of the former. To what extent the insurance companies are annually the losers through this crime it is impossible to say. A good system of fire coroners in our country would do much to lessen the number of such losses, as well as to give us more reliable statistics. Australia, which has led the English-speaking world in many useful reforms, has tried this system. The following editorial notice in the *Chronicle* (April 13, 1893) gives us an idea of the results to be expected and the importance of the work.

"The *Australasian Insurance and Banking Record* publishes a record of inquests on fires in New South Wales in 1892, which should interest the fire inquest people in the United States. The total number of inquests was 139, but in ninety-one cases the evidence was so incomplete that the fire coroners could not decide whether the fire originated accidentally or was caused by an incendiary act. Out of forty-eight cases in which the coroner reached conclusions, nineteen fires were decided to have had accidental origins, while twenty-nine fires were attributed to arson. In other words, sixty per cent. of the fires whose causes were ascertained were incendiary and the remaining forty per cent. accidental. This abnormally large percentage of incendiarism will create surprise, even among those American fire underwriters who are most suspicious of the honesty of policy-holders. The Australasian coroners' decisions would appear more trustworthy if the proportion of their indecision was not so large. No information is given by the *Record* as to the number of alleged incendiary fires in which insurance policies were involved."

Man's domestic customs and habits undergo fewer mutations than do the operations of his business life.

In the latter he is quick to appreciate and to follow im-

proved methods, but in the construction of his dwellings and in his manner of life within their walls he clings tenaciously to practices which have long outlived their usefulness.

It is our purpose to confine ourselves at present to a consideration of the *causes* of fires, interesting as might be a study of the historical evolution of our dwelling-houses, a comparison of our homes with the *οἰκία* of the Greeks, or with the houses and *insulæ* of the Romans, with whom the tenement house, generally supposed to be a modern institution, was not wanting, or a contrast between the English homes of the time of Shakespeare (so charmingly described by William Harrison, in *Hollinshed's Chronicles*, 1577, Book II, Chapter 10; 1587, Book II, Chapter 12,) and those of the present day. But why, it is pertinent to inquire, do we not introduce in our dwelling constructions the slow-burning principles now universally employed in properly built manufactories, many of which could advantageously be utilized without deteriorating the æsthetic effect?

The majority of fires in dwellings are caused by heating and lighting apparatus.

The heating apparatus of a house should be centralized as much as possible. One fire is by far less hazardous than a number of them, for every one is an additional source of danger. Whatever system may be used, whether hot air, steam, or hot water, great care must always be exercised that inflammable substances are not placed in the immediate neighborhood of the heating apparatus.

Two things in every household, which frequently fail to receive the proper amount of attention, and which, in view of their importance, should be erected only by the best workmen, are the systems of drainage and heating. A defect in the first menaces health, and in the second involves danger from fire. We frequently find that in erecting heating apparatus, no thought has been given to the fact that heat will expand substances, and especially metals, to a considerable degree. This negligence in construction causes the formation of cracks and breaks which allow sparks to penetrate into the surrounding air. Where hot-air registers are used in floors (if possibly avoidable do not have them) cover the openings

with wire netting; especially in places where dirt and other refuse are apt to drop in, or where children could throw inflammable substances into them. At least one register in every house should be so arranged that it cannot be closed, for many fires are caused by hot-air flues becoming overheated when all registers are closed and the hot air cannot escape. Strict cleanliness in every detail of heating arrangements, is of prime importance, and before "firing up" in autumn the entire apparatus should be thoroughly examined. New heating apparatus is especially dangerous, as it has not stood a trial. Be specially on the alert in very cold weather, as artificial heating must then be increased to a dangerous degree.

Separate stoves should not be put up in out-of-the-way rooms. See that your central heating apparatus gives satisfaction, as frequently these stoves are neglected and cause fires. Stoves should be free from cracks and the floor protected by pieces of metal under them. These metal protectors should be amply large, so that hot coals which may fall from the stoves may be received on them, and not fall on the wooden floor or carpet. Brick platforms are not as safe as tin, as stoves are not apt to remain as stable on brick as on metal. Stoves should never be placed on ash receptacles, as they afford little stability and tend to cause stoves to lean and upset. The plastering of walls around stoves should be unbroken, and particular care should be taken that laths are not exposed to the escaping sparks. Wood-work near stoves should be protected with bright tin, which acts as a reflector to the heat rays, while a black or rough surface absorbs them. The storing or piling of wood near stoves is a frequent cause of fires. Particular care must be paid to stove-pipes to keep them at all times sound and in good order. They should never enter chimneys at points which cannot at all times be inspected, such as unused rooms, closets, and the like; nor should a stove-pipe extend through any place where it is not at all times visible, as fires may be caused by the accumulation of dust and fine organic matter upon it. The tops of

stove-pipes should be frequently looked after and cleaned. The joints or elbows of pipes should be well riveted, so that sparks may not be ejected through the breaks, and the entire pipe should be well supported by wire hangers or braces. Where pipes pass into chimneys they should be well fastened by a metal or terra-cotta collar, which, as well as the pipe, should be tightly wedged into the opening so that the pipe cannot disengage and thereby emit sparks into the room. Care must be taken never to allow stove-pipes to enter a flue vertically, as soot which may accumulate in the pipe is readily ignited and may cause larger fires. Stove-pipes should never pass out of the sides of a building or through windows.

Ashes should be kept in metal receptacles, never in wooden, or as is sometimes the case, in pasteboard boxes. Ashes have the remarkable property of holding heat for a long time, and for this reason ashes which are seemingly cooled should never be placed in wooden barrels and stood alongside of frame buildings or fences, as several cases are known in which spent ashes on being piled in quantity again became heated and ignited adjacent wood-work. All chimney flues should be properly "pargeted" on the inside, the brick-work should be of sufficient thickness between the floors or studding, and all wood-work should be well trimmed away from flues with safe air spaces between. Before plastering the inside, however, the architect, or better still, the proprietor, should see that the bricks of the chimney are solidly laid in mortar and well pointed. Many chimneys are laid almost dry, and when the plastering drops off such chimneys become exceedingly dangerous.

Instead of laying brick or stone on planks and flooring to form hearths, the latter should be protected by brick arches. This is the safest method. If brick arches cannot be so placed, then a layer of thick asbestos paper or concrete should first be laid on the wood-work, upon this a layer of sand and concrete, and then bricks laid in good cement; upon this another layer of bricks should be laid, but in such a manner as to leave an air space between it and the preceding course.

The safest system of heating is by hot water. In this case, the room is heated by radiation from pipes filled with water which has been heated in a boiler, preferably outside of the building to be heated.

Steam is now frequently employed for heating dwellings. Special care must be taken to hang pipes free from woodwork and away from all places where dust, dirt, sweepings and so on may accumulate. Where it is possible, as in tenement houses, servants' apartments, store-rooms, etc., steam pipes should be hung along the ceiling, about twenty-four inches below it (as is the usual method in the best modern factory buildings), instead of along the sides of the room as in the old fashion. The theory, often advanced, that with pipes hung below the ceiling, the same amount of heat cannot be obtained as when placed along the sides of the room, is erroneous. The following table, which shows the results of a series of experiments made by Mr. C. J. Woodbury, demonstrates this.

Hourly thermometrical observations were taken in a room 75 x 400 feet, supplied with five rows of steam pipes. In the first instance, the pipes were placed against the walls near the floor, and in the second there were four rows of pipe around the room, two feet from the walls and hung the same distance below the ceiling, requiring only three-quarters as much pipe as in the first instance.

MEAN TEMPERATURE OF HOURLY READINGS.

Thermometers Hung in Centre of Room.	Degrees Fahrenheit.	
	Pipes at Side. Dec. 29th to Jan. 5th.	Pipes Elevated. Jan 29th to Feb. 5th.
Sixteen inches from ceiling,	80·05	80·80
Midway,	76·52	76·90
Sixteen inches from floor,	77·08	77·00
Average,	77·88	78·23

The reasons why steam pipes ignite wood are twofold: (1) By allowing the water to run low, the steam becomes superheated, causing a true combustion, and (2) pipes

containing steam at the usual temperature may cause the secondary phenomenon of spontaneous combustion. In the latter case, the steam pipes slowly dry the wood, the contained moisture being vaporized, and at last the wood assumes a state resembling charcoal; whereupon the glowing or combustion, well known in the case of charcoal, takes place spontaneously.

At a discussion of the French Academy, in 1879, this was brought out clearly. M. Cosson described an accident which had occurred in his laboratory a few days before. While the narrator was working in the laboratory, a portion of the boarding of the floor spontaneously took fire. The boards were in the vicinity of an air hole, fed with warm air from a stove four metres away on the floor below. A similar accident had taken place a few years before, and in consequence M. Cosson had replaced the boards adjoining the air hole by a slab of marble. The boards which now ignited adjoined the marble. The heat to which the boards were subjected was, however, very moderate, being only that of warm air at 25° C. Nevertheless, M. Cosson said the wood had undoubtedly been slowly carbonized. Being thus rendered extremely porous, a rapid absorption of the oxygen of the atmosphere had resulted and sufficient caloric was thereupon produced to originate combustion. The danger thus disclosed, said M. Cosson, is one to which the attention of builders ought to be directed. In the instance in question, M. Cosson was able to extinguish the fire with a little water, as he was present and witnessed its beginning; but had it occurred at night, during his absence, it would undoubtedly have completed its work of destruction. M. Fayé stated that at Passy, a few days before, a similar case of spontaneous fire, due to the action of the warmth from the air hole of a stove upon the woodwork, had occurred at the house of one of his friends.

Mr. C. C. Hine, the veteran editor of the *Monitor*, expatiates on this topic as follows: "The Institute of Technology, of Boston, long ago decided upon the danger of steam pipes passing through and in contact with wood. It was shown that the wood, by being constantly heated, assumes the

condition, to a greater or less degree, of fine charcoal, a condition the most favorable to spontaneous combustion. This is so important and interesting a point that we may be pardoned for enlarging upon it somewhat in contrast to the brevity of the foregoing paragraphs.

"Steam was generated in an ordinary boiler and was conveyed therefrom in pipes which passed through a furnace and thence into retorts for the purpose of distilling petroleum. Here the pipes formed extensive coils and then passed out, terminating at a valve outside the building. To prevent the steam, when blown off, from disintegrating the mortar in an opposite wall, some boards were set up to receive the force of the discharge, and as often as the superheated steam was blown against them, the boards were set on fire! This occurred in an oil refinery in Pittsburg, Pa.

"Some years since, while on a visit at the Institution for the Deaf and Dumb, in Illinois, of which an esteemed friend is principal, we called attention to the manner in which some steam coils were secured to wooden supports, and pronounced them unsafe. They were shown to be a thousand feet or so—as the pipes ran—from the boiler, and our caution only provoked a smile. The next year we visited, as usual, and, upon taking the principal's hand, he said—before exchanging salutations or inquiries: 'Come with me; I wish to show you something,' and led the way to the room where, a year ago, his attention had been called to the steam pipe. 'There,' said he, 'examine that; I have been saving it for you since last winter; the coil fell down, and investigation showed that the screws had let go because the wood had been turned to charcoal and had no more strength to hold them.' The experience was new to him; it may be old to some of our readers, but its introduction here will illustrate a fact which is now becoming an admitted one among those who have given this matter attention.

"An experiment illustrating the effects of superheated steam was tried as follows: Steam was taken from an ordinary boiler through a pipe forty feet long. Ten feet from the farther end a collar of wood was fitted closely to the pipe; ten feet nearer the boiler a lighted kerosene lamp

was placed under the pipe. In ten minutes the wooden collar was on fire."

To resume our text, then, carelessness causes the greatest number of fires: carelessness in regard to heating, and lighting and in storing inflammable and self-inflammable substances. We pass now to the next series of hazards, those of lighting.

The usual method of lighting in the larger cities of America is by gas. The greatest care must be taken to arrange fixtures so that they cannot swing against combustible substances, such as curtains and woodwork. Swinging brackets are largely responsible for fires in dwellings, and should, as much as possible, be done away with. A gas flame is the producer of intense heat, tending to thoroughly dry all substances around it and transform them into a state ready for ignition. A systematic arrangement and solid construction of the entire system of gas supply throughout a house is of prime importance. Frequently, the installation of gas fittings is left to "cheap" employés or apprentices, and this, of course, carries serious results with it. Not only do fires originate through leaking gas pipes, but many lives also have been lost by gas poisoning and suffocation. A valve which cuts off the main supply, to which any member of the household can readily have access, and which *can be turned without trouble*, is of great importance, as sometimes it is impossible to stop leaks without the aid of a mechanic, and fires have been caused by persons going into rooms with lights "searching for the leak." They usually find it by this method; not, however, in a manner agreeable to themselves.

In installing a system of gas lighting, particular attention must be paid that every gas flame, which, through the heat which radiates from it, forms a certain globe or radius of danger around it, is at a safe distance from inflammable substances. A gas flame should be at least thirty-six inches from the ceiling, and when nearer to an inflammable substance than this, the latter should be covered with metal, care being taken to allow an air space between the metal and the wood or other inflammable substance, so that it

cannot be ignited or charred by conduction, which might otherwise be the case. Where swinging brackets are used (avoid them wherever you can), these should be provided with stops to prevent them from swinging against woodwork. A very good method of arranging gas lights, which has not been carried out in dwellings, but which is required in theatres, is to place wire baskets or cages around them. These cages are made of wire, and attached to the bracket. The gas can be readily lit by protruding a lighted taper or match between the wires (electric lighters now generally introduced make the ignition of gas still easier) while the globe of wire prevents combustible substances from coming in contact with the flame or inside of the sphere of danger. Such cages should by all means be fastened to those long swinging brackets in chambers, which are usually found near windows on both sides of looking glasses. It will be objected that the wire guards in theatres are unsightly, but these devices could be made of brass in beautiful designs so as to be an ornament. If a window be opened a draught blows the lace curtain into the flame, and a fire results. This winter, a number of fires were caused in Philadelphia by persons who in attempting to light the gas from such brackets near window curtains, succeeded in igniting the latter.

Where Siemens regenerative burners are used, ventilating flues should carry off the heat generated and the products of combustion. These flues should be well constructed of metal, free from woodwork, as large burners of this kind give off a great amount of heat.

Petroleum is much used for lighting in smaller dwellings, and in reading lamps, thanks to Philadelphia gas, even in finer residences. In order to be fit for use it should have a flash test of at least 130°. This can readily be tested by pouring some of the oil into a dish placed on a layer of sand contained in another receptacle, so that the heat may be distributed evenly throughout the oil, applying heat to the outer receptacle containing the sand, and placing a thermometer in the oil. An ignited taper (the flame as small as possible, so as not to heat the oil on the surface) is then held above

the oil, but not allowed to touch it. The temperature of the oil is then accurately observed, and if the vapor from the oil flashes before it has a temperature of 130°, it is unfit for use in households.

It is exceedingly difficult to extinguish petroleum fires, and the explosiveness of this substance is well known, as there is scarcely a week, or even a day, in which we do not hear of some sad accident caused by this substance. *Do not, therefore, attempt to light fires with petroleum.*

Dr. Schlumberger, who has given his special attention to this subject, some years ago stated that, according to the statistics which he had collected, out of ten persons who attempt to extinguish burning petroleum, six are killed.

Frequently dealers adulterate oils by mixing heavy oils with lighter and more explosive products. Petroleum is composed of the elements of carbon and hydrogen, and its products range, by almost imperceptible degrees, from oils which are very light and inflammable, to those of a consistency of molasses, which can only be ignited at very high temperatures.

The following are the principal products obtained by the distillation of crude petroleum, but chemists have obtained by fractional distillation many other substances holding intermediate positions in the list and to these they have given as many different names.

	Specific Gravity Water, 1.	Specific Gravity Baumé.	Boiling Point. Fahr.
Rhigolene,	·625	—	65°
Gasoline,	·665	·85	120°
C-Naphtha,	·706	·70	180°
B-Naphtha,	·724	·67	220°
A-Naphtha,	·742	·65	300°
Kerosene oil,	·804	·45	350°
Mineral sperm oil,	·847	·36	425°
Neutral lubricating oil,	·883	·29	575°
Paraffine,	·848 (?)	—	—

The explosiveness and inflammability of an oil, however, do not depend upon its specific gravity, for the oil may not

be a stable one but a mixture of a lighter and a heavier oil, so that while the hydrometer may show its specific gravity to be comparatively high, it may be an extremely dangerous oil, as, on a slight elevation of temperature, the lighter constituent will be given off in the form of vapor.

[*To be continued.*]

THE COMMITTEE ON SCIENCE AND THE ARTS OF THE FRANKLIN INSTITUTE.

REPORT NO. 1706.

Subject—MARKS' IMPROVEMENTS ON ARTIFICIAL LIMBS.

At the stated meeting of the Committee on Science and the Arts of the Franklin Institute, held February 1, 1893, the following report was adopted and ordered to be issued over the signature of the Chairman and the certification of the Secretary, viz:

This invention consists of an improved method of making artificial limbs, adapted to amputations in the ankle, or below, in the tarsus or metatarsus in which the former modes of construction, with articulated ankle joints of wood as the material, were impracticable and unsatisfactory in result; although sometimes made when wood was employed as a material, these were always clumsy, and when the articulated ankle was attempted, it proved inoperative. The new method of construction involves the use of aluminum as the material to form the shell socket or sustaining frame, as it might be called, the aluminum shell supporting the body, and forming the attachment for the elastic rubber foot, which acts as a rolling elastic segment simulating the functions of the natural foot in walking, and acting as an elastic cushion in relieving the wearer from the jar or shock of resting the weight upon the limb. At the same time they resemble the form of the natural foot more closely than was possible with previous constructions.

The invention is described and set forth in United States Letters Patent, No. 470,431, to George E. Marks, of New York City, N. Y., dated March 8, 1892.

The specimen submitted to the committee shows the invention to be extremely light and so compact as to make no noticeable enlargement of the artificial foot beyond the size of the natural foot, thus completely restoring the appearances. The elastic portion of the foot is attachable and removable, and by its own elasticity retains its position upon the aluminum shell or form.

Your committee has examined the limbs in the course of manufacture, and as completed and as in use by wearers. When clothed, they give no indication in walking that they are not natural feet. Of course, there is not that extension which an ankle joint provides when the wearer is sitting, which, sometimes, and often occurs in the natural foot under such conditions, but this is true of all artificial limbs, unless special pains and an awkward effort is made to produce this motion. An artificial ankle joint requires pressure upon the heel to extend the foot.

The mode of making the aluminum shells consists in first producing a plaster cast of the mutilated member to which it is to be applied. Upon this plaster cast is fitted a pattern carved in the usual manner from wood, and prepared by varnishing for the founder. The aluminum shell is then cast from this pattern in a sand mould, removed from the mould when cold, and filled, straightened and polished with the usual workshop appliances, so that the shell of the limb is an internal piece of metal.

The extreme lightness of the metal is not the only advantage; there is also another of great importance. The aluminum does not absorb moisture, is not corroded by perspiration, or the excretions from the skin, or from the sores which unfortunately are too often found in a mutilated member, and it is readily cleansed by washing, not being liable to injury from water or moisture, or the heat incident to any climate. The leather portions are so readily detached, renewed and attached as to give promise of a far longer term of usefulness with less expense and trouble than has heretofore been attained in any other structure for the same purpose.

The drawing appended shows the invention in sections.

The elastic rubber foot is applied and renewed in the same manner and with the same facilities as an elastic overshoe.

The limb embraces four elements: First of these is the metallic shell or frame: its functions are to receive the weight of the wearer at its upper part, and transmit it to the foot.

This is the most expensive part of the structure, is not susceptible of corrosion under any conditions in which it is subjected in use; is strong, light and compact, and conforms closely to the form and dimensions of the limb which it simulates, and is of great durability.

The second is the removable elastic foot: this is so proportioned in thickness in its several parts as to hold securely

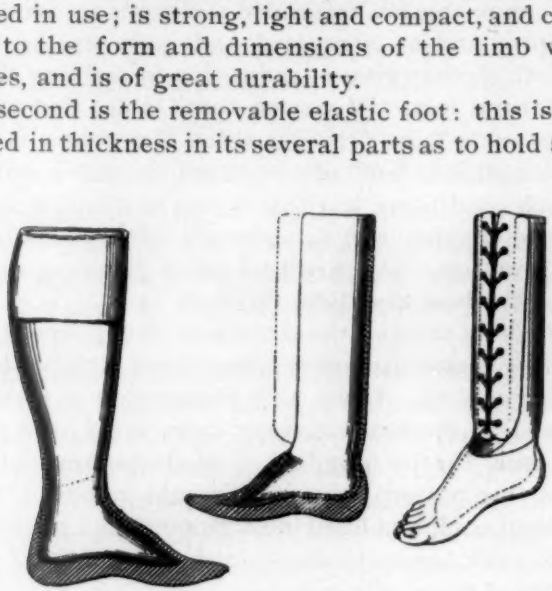

FIG. 1.

on the lower portion of the frame and to act as an elastic cushion in receiving the weight upon the heel and transfer it as the step progresses to the ball of the foot and toes, which, under the pressure, flex, and again extend as they are relieved of weight, thus closely imitating the action of the natural foot.

Being removable as easily as a rubber shoe, a new one from the same mould can be promptly and cheaply substituted when the original is worn out.

The third element in the structure is the leather jacket which confines the limb in the metallic shell or frame so that the weight is received on the upper portion.

This jacket of leather is attached to the shell by a few rivets, which can easily be removed and a new leather expeditiously substituted at small cost by any saddler or other leather worker without entailing the delay of sending the limb to the original manufacturers.

The fourth and last element is the pad in the base of the cavity of the aluminum shell or frame; this is not designed to support the weight of the wearer and does not necessarily make any contact with the stump, but is merely a protection to the wearer from the sensation of cold incident to close proximity of the metal.

The pad is made of cork in the specimen submitted and covered with felt on the upper surface, a pad of wool or any

FIG. 2.

other similar substance could be substituted with like effect; the cork has the advantage of being light, and is easily removed, cleaned and replaced.

The combination of these parts forms a limb which, with inexpensive repairs, easily procurable with little delay, has almost unlimited durability and affords a much needed relief to many who heretofore were dependent upon crutches for aid in locomotion.

The invention, regarded from a humanitarian standpoint, is of great importance. Although it was less than two years from the making of the first specimens, at the time this invention was shown at the Institute and referred by resolution to the committee for examination, yet 134 at that

time had been brought into practical use, as appears from an inspection of the books and correspondence of the manufacturers, and all of them found to be satisfactory in performance.

Such a practical endorsement from the users and those only fully qualified to test the merit of this class of inventions is indicative of the great merit and suggestive of the extended field of usefulness of the invention.

The following, from the impression of the *New York Medical Journal*, of April 16, 1892, sets forth better the importance of the invention from a humanitarian standpoint, as viewed by surgeons than your committee feel competent to express in any other terms:

"There are amputations of the lower limbs that surgeons deem desirable to do without sacrificing more of the member than the parts involved. We refer to amputations technically termed tibio-tarsal, tarso-metatarsal and medio-tarsal. These amputations have always been in disfavor with artificial limb makers, who have almost unanimously decried them, and, in too many instances, have persuaded the surgeons to sacrifice much of a healthy leg merely to obtain a stump that would better accommodate the artificial limbs that they were able to produce.

"The new artificial leg, constructed of aluminum combined with the rubber foot, is adaptable to these amputations. The socket of aluminum incases the stump, and on account of the strength of the metal the socket does not increase the diameters of the ankle to an objectionable degree in order to obtain the requisite strength. The metal is cast into the proper shape to give ease and comfort to the wearer, the aluminum socket is terminated by a rubber foot, which not only simulates the natural foot, but provides a soft springy medium to walk upon and a resistent phalangeal ball to rise upon while walking, running or ascending stairs.

"It is obvious that by this invention the amputation can be conditional upon the injury and the artificial limb conditional upon the amputation. In this alone the invention of the aluminum and rubber leg will prove not only a boon to the one who has suffered the amputation, but the solution of a problem that has many times perplexed the operating surgeon, as it eliminates all the objections heretofore pressed against amputations in the region of the tarsus. The surgeon may thus rejoice in being able to observe the old and consistent law of amputating with the least sacrifice."

It is, therefore, clearly apparent that the invention is one affording much needed relief to persons heretofore greatly embarrassed, and further that the surgeons may save much more of the patient's body from mutilation than heretofore,

and yet render comfortable and satisfactory artificial limbs practicable.

In view of these points of excellence and the well-attested evidence thereof, the committee awards the Elliott Cresson Medal to George E. Marks, of New York, for his improvements in artificial limbs.

Adopted, February 1, 1893.

H. R. HEYL,
Chairman Committee on Science and Arts.

Certified as a correct copy.

W. H. WAHL, *Secretary.*

THE CHEMICAL SECTION

OF THE

FRANKLIN INSTITUTE.

[*Proceedings of the special meeting held Thursday, June 8, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 8, 1893.

Dr. WM. H. GREENE, President, in the chair.

The object of this meeting was to afford the members the opportunity of hearing a lecture by Dr. Ernest Milliau, Director of the Government Testing Laboratory at Marseilles, France, on "The Methods of Testing Fats and Oils."

The lecture was delivered for the purpose of furthering the adoption of uniform methods of testing and of expressing results.

A vote of thanks to the lecturer was carried, and it was voted also to refer the lecture for publication in the *Journal* as part of the proceedings of the Section.

Adjourned.

WM. C. DAY, *Secretary.*

[*Proceedings of the Stated meeting, held Tuesday, June 20, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 20, 1893

Dr. WM. H. GREENE, President, in the chair.

Letters from Prof. E. F. Smith and Mr. Lee K. Frankel were read, expressing regret at their inability to be present at the meeting.

The President announced the death of Mr. C. J. Semper. Dr. Terne spoke of the work and character of the deceased, and the President

appointed Dr. Terne and Dr. Wahl members of a committee to prepare a memorial; he also gave them authority to appoint a third member.

The proceedings of the special meeting of the Section, held June 8th inst., were ratified by a unanimous vote.

Dr. Terne then read a highly interesting paper on "The Rational Utilization of City Garbage." This paper was very opportune, in view of the steps now being taken in Philadelphia to cremate and thus totally destroy garbage for sanitary reasons. Dr. Terne advocated the adoption of a system by which a saving of the valuable oil and fat ingredients of garbage could be effected, while the residue from this could be utilized as a valuable fertilizer. The members of the Section were unanimous in indorsing the view of Dr. Terne that garbage could be so utilized with a saving of much valuable material which is ordinarily wasted, and under the system of cremation totally destroyed. They also agreed that the ends of sanitarians would be just as effectively secured by the proposed system as by the wasteful process of cremation. The author further described some of the details of treating the garbage for the purpose he advocated, and exhibited samples of products, such as oils, solid fats and fertilizing material, which he had already secured on the large scale.

The Secretary then read a paper by Mr. Lee K. Frankel on "Gelatinous Silver Cyanide," and also exhibited a specimen of the compound submitted by the author.

The Section then adjourned.

WM. C. DAY, *Secretary.*

A LIST OF ELECTRICAL JOURNALS, 1893.

Compiled by Carl Hering.

AMERICAN.

Title.	*Published Where.*	*When.*	*Subscription.*
Electrical World,	New York.	Weekly.	$3 00
Electrical Engineer,	New York.	Weekly.	3 00
Western Electrician,	Chicago.	Weekly.	3 00
Electrical Review,	New York.	Weekly.	3 00
Electricity,	New York, Chicago.	Weekly.	2 50
Electrical Age,	New York.	Weekly.	2 00
Mechanic and Electrician,	St. Louis.	Weekly.	2 00
The Railroad Telegrapher,	Vinton, Ia.	Fortnightly.	1 50
Practical Electricity,	Boston.	Fortnightly.	2 00
Trans. Amer. Inst. Electrical Engineers,	New York.	Monthly.	5 00
Electrical Power,	New York.	Monthly.	2 00
Popular Electric Monthly,	Chicago.	Monthly.	1 00
Electrical Progress and Development,	Boston.	Monthly.	2 00
World's Fair Electrical Engineering,	Chicago.	Monthly.	
Electrical Industries,	Chicago.	Monthly.	
Mechanical and Electrical Progress,	Philadelphia.	Monthly.	
Journal of the Telegraph,	New York.		
Electric Spark,	Chicago.	Monthly.	1 00
Northwest Electrician and Mining Review,	Tacoma.	Monthly.	1 00
Bubier's Popular Electrician,	Lynn.	Monthly.	50
Electricity and Railroading,	Boston.	Monthly.	1 00
Street Railway and Electrical News,	Minneapolis.	Monthly.	2 00

FOREIGN.

In the English Language.

			(In the U. S.)
Electrician,	London.	Weekly.	19*s.* 6*d.*
Electrical Engineer,	London.	Weekly.	13*s.* 0*d.*
Electrical Review,	London.	Weekly.	£1 1*s.* 8*d.*
Electricity and Electrical Engineering,	London.	Weekly.	
Lightning,	London.	Weekly.	
Canadian Electrical News,	Toronto, Montreal.	Monthly.	$1 00
Journal of Institution of Electrical Engineers,	London.	Monthly.	
Electrical Plant (Electrical Industry),	London.	Monthly.	6*s.*

In the French Language.

Title.	*Published Where.*	*When.*	*Subscription.*
La Lumière Électrique, ...	Paris.	Weekly.	60 francs.
L'Électricien, ...	Paris.	Weekly.	25 francs.
Électricité, ...	Paris.	Weekly.	15 francs.
Bulletin de l'Électricité, ...	Paris.	Weekly.	15 francs.
Journal du Gaz et de l'Électricité, . . .	Paris.		
L'Industrie Électrique, ...	Paris.	Fortnightly.	26 francs.
Bulletin de la Société Internationale des Électriciens, ...	Paris.	Fortnightly.	27 francs.
L'Électricité pour Tous, ...	Paris.	Fortnightly.	6 francs.
Journal Télégraphique, ...	Berne.	Monthly.	
Bulletin de la Société Belge d'Électriciens, ...	Belgium.	Every 2 months.	
Bulletin de l'Association des Ingenieurs Électriciens Sortis de l'Institute Électro-Technique Montefiore, . .	Belgium.	Quarterly.	

In the German Language.

Elektrotechnischer Anzeiger, ...	Berlin.	Bi-weekly.	10 mark.
Elektrotechnische Zeitschrift, ...	Berlin.	Weekly.	25 mark.
Elektrotechnische Rundschau, ...	Frankfurt.	Fortnightly.	10 mark.
Elektrotechnisches Echo, ...	Magdeburg.	Weekly.	
Zeitschrift für Elektrotechnik, ...	Vienna.	Fortnightly.	

BOOK NOTICES.

Municipal Improvements. A Manual of the Methods, Utility and Cost of Public Improvements for the Municipal Officer. By W. F. Goodhue, Civil Engineer. First edition. First thousand. New York: John Wiley & Sons. 1893.

In this little work the author proposes to place in the hands of the intelligent and well-meaning but as yet uninstructed city councillor or other person charged with some responsibility for the construction and maintenance of public works, a guide to a general and correct understanding of the subjects with which he in his official capacity has undertaken to deal.

The author has used good judgment in the selection of his subjects, the amount of information to be imparted respecting each and the manner in which it should be presented. He has wisely avoided the danger, ever present with the writers of such works, of saying too much, and has, perhaps, erred a little on this safe side. Considering the character of his audience, we are inclined to think that a little too much information on their part respecting the A, B, C's is taken for granted.

Certainly the list of illustrations might have been advantageously

extended. There are but seven cuts in all—a diagram of cellar drainage being all that is given to illustrate "A Sewerage System," a diagram of stand-pipe connection for "A Water Works System"—and so on.

Still, the book, which is well got up, ought to be well worth its cost to the conscientious ones among those for whom it is intended. T.

Laboratory Calculations and Specific Gravity Tables. By John S. Adriance, A.M. Second edition. New York: John Wiley & Sons. 1893.

This book, of 114 pages, contains many tables useful to chemists. The title indicates its character. We will take the liberty here of pointing out one or two errors. On p. 46 is given a table showing the specific gravities corresponding to degrees Beaumé, for liquids heavier than water. In it, 66° B. equals sp. gr. 1·767. This is incorrect for the instruments used in the United States, where 66° always corresponds to 1·8354 sp. gr. The correct table will be found printed on the green case in which the instrument is packed.

Again, on p. 36, we find a table for converting milligrams per litre to grains U. S. gallon; on p. 94, a table of fluid measure, in which 160 fluid-ounces equals one fluidgallon, thus showing that the Imperial gallon is referred to; and, on p. 96, we have again the U. S. gallon of 231 cubic inches. This confusion of American and English measures should be avoided, by stating which gallon the table refers to. P.

Franklin Institute

[*Proceedings of the stated meeting, held Wednesday, June 21, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 21, 1893.

JOSEPH M. WILSON, President, in the chair.

Present, thirty-five members and five visitors.

Additions to membership since last report, nine.

The Secretary read a report signed by Messrs. Joseph M. Wilson, Henry R. Heyl, Jno. C. Trautwine, Jr., and George V. Cresson, constituting a special committee appointed under a resolution of the Institute, passed at the stated meeting of March 15, 1893, to examine and report upon the proposed amendments to the regulations of the Committee on Science and the Arts. The Special Committee reported that they had performed the duty assigned to them, and "found that the proposed regulations are in conformity with the charter and by-laws of the Franklin Institute, and in no respect conflict with the same." The committee recommended "that the proposed regulations be approved by the Institute, and ask to be discharged."

The report and recommendation of the Special Committee were, thereupon, on motion, adopted and the committee was discharged.

The Secretary read a letter from Mr. George V. Cresson, accepting his election as a Trustee of the Elliott Cresson Medal Fund, in place of Mr. Samuel Sartain, resigned.

The Secretary reported a vacancy in the Committee on Science and the Arts caused by the death of Mr. Walter H. Balliet. Mr. J. Logan Fitts was elected to fill the vacancy.

Mr. Thomas Shaw described and exhibited in operation an apparatus of his invention for determining the explosive force of gunpowders for small arms. The subject was, on motion, referred to the Committee on Science and the Arts, for examination and report.

Dr. Bruno Terne presented in abstract a paper treating of the question of the disposal of the garbage of large cities. The speaker discussed the relative merits of the system of cremating such refuse materials and of utilizing the grease, nitrogenous and mineral substances contained therein, and advocated the latter as the rational and proper method of dealing with them. He explained that the garbage of several cities in the United States was successfully utilized, instancing Detroit, Cincinnati and St. Louis as examples, and gave an account of some experiments in this direction on the large scale, which he had of late been conducting at the works of the Baugh & Sons Company, Philadelphia. He exhibited a number of specimens of the products obtained, and affirmed that the utilization of the large quantities of city garbage now practically wasted was attended with no serious technical difficulties, and could be made commercially profitable.

Mr. E. G. Acheson, of Monongahela City, Pa., read a paper on "Carborundum: Its History, Manufacture and Uses," illustrating the subject by the exhibition of specimens of the product, and of various forms of cutting wheels made therefrom. (Referred for publication)

Mr. W. N. Jennings presented a number of lantern slides of local interest, which were well received.

The Secretary exhibited a reproduction of an ancient clock, styled the "Columbus Clock," affirmed to be an exact reproduction of the timekeepers in vogue at the close of the fifteenth century. The instrument was exhibited on behalf of the Bostwick & Burgess Manufacturing Company, Norwalk, O.

Under new business, the subject of the proposed amendments to the Institute's by-laws, increasing the annual dues of members and the fee for life membership, was brought forward. A motion was made and carried to proceed with the publication of the proposed amendments and postpone consideration and action thereon until the next stated meeting.

Adjourned.

WM. H. WAHL, *Secretary.*